Monitoring and Assessment of Fish Habitat Compensation and Stewardship Projects: Study Design, Methodology and Example Case Studies

M.P. Pearson, J.T. Quigley, D.J. Harper, and R.V. Galbraith

Oceans, Habitat and Enhancement Branch
Fisheries and Oceans Canada
200 - 401 Burrard Street
Vancouver, BC
V6C 3S4

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MONITORING AND ASSESSMENT OF FISH HABITAT COMPENSATION AND STEWARDSHIP PROJECTS: STUDY DESIGN, METHODOLOGY AND EXAMPLE CASE STUDIES

by

M.P. Pearson[1], J.T. Quigley, D.J. Harper[2] , and R.V. Galbraith[3]

Oceans, Habitat and Enhancement Branch
Fisheries and Oceans Canada
200 - 401 Burrard Street
Vancouver, BC
V6C 3S4

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[1] Pearson Ecological, 2-650 East 12th Avenue, Vancouver, BC V5T 2H8
[2] Habitat Protection and Sustainable Development Branch, Fisheries and Oceans Canada, 200 Kent Street, Ottawa, ON K1A 0E6
[3] Author to whom all correspondence should be addressed: GalbraithR@pac.dfo-mpo.gc.ca

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ABSTRACT

Pearson, M.P., Quigley, J.T., Harper, D.J., and Galbraith, R.V. 2005. Monitoring and assessment of fish habitat compensation and stewardship projects: Study design, methodology and example case studies. Can. Manuscr. Rep. Fish. Aquat. Sci. 2729: xv + 124 p.

We present a three-level strategy for monitoring and evaluating fish habitat compensation and stewardship projects. Basic routine monitoring is applied to stewardship projects and to minor compensation projects (e.g. small riparian planting projects). More rigorous and quantitative site effectiveness monitoring, emphasizing paired before-after control-impact (BACIP) experimental designs, is applied to larger and/or more complex compensation and stewardship projects. We stress the most important principles outlined in this guidebook (establishing measurable objectives, reference and control sites, replication, and pre-impact information) as the key elements upon which to focus any monitoring program. Program effectiveness evaluation, which applies adaptive management methods to studies involving multiple projects, is recommended using standard methods. Study design and appropriate methods are discussed for all three monitoring levels and detailed descriptions of suitable analytical techniques for assessment of no-net-loss of fish habitat are included. Four case studies are used to illustrate application of the routine and site effectiveness monitoring methods presented.

RÉSUMÉ

Pearson, M.P., Quigley, J.T., Harper, D.J., and Galbraith, R.V. 2005. Monitoring and assessment of fish habitat compensation and stewardship projects: Study design, methodology and example case studies. Can. Manuscr. Rep. Fish. Aquat. Sci. 2729: xv + 124 p.

Nous présentons une stratégie à trois niveaux de surveillance et d'évaluation des projets de compensation et d'intendance de l'habitat du poisson. La surveillance de routine qualitative est appliquée aux projets d'intendance qui ne comportent pas de détérioration, destruction ou perturbation de l'habitat des poissons, et à des petits projets de compensation (p. ex. les petits projets de plantation de végétaux riverains). La surveillance quantitative de l'efficacité des sites met l'accent sur la méthode expérimentale dite BACIP (*avant-après, témoin-impact appareillé*) et est appliquée à des projets de compensation et d'intendance plus grands et/ou plus complexes. Des méthodes standards régionales sont utilisées pour recommander des modes de surveillance et d'évaluation des programmes, modes de surveillance et d'évaluation faisant intervenir des méthodes de gestion souple des études comportant des projets multiples. Les divers concepts d'études et les méthodes adéquates sont examinés pour les trois paliers de surveillance, et des examens détaillés des techniques analytiques qui s'imposent pour évaluer l'atteinte de l'objectif d'aucune perte nette d'habitat du poisson sont fournies. Quatre études de cas servent à illustrer l'application des méthodes présentées.

EXECUTIVE SUMMARY

BACKGROUND

The overall objective of Fisheries and Oceans Canada's (DFO) Policy for the Management of Fish Habitat (the Habitat Policy) is to achieve a net gain (NG) in the productive capacity of fish habitats by conservation, restoration, and creation of fish habitats. To achieve this, DFO leads or reviews most fish habitat projects in Canada, as well as funds a significant number of projects. Most of these fish habitat projects can be divided into two categories: compensation projects and stewardship projects. Both are undertaken to ensure that the achievement of an overall NG of the productive capacity of fish habitats is realized, and both can be used to promote public awareness of the importance of fish habitats. They differ primarily in that compensation projects are undertaken to balance an unavoidable loss in productive capacity as a result of a harmful alteration, disruption, and destruction of fish habitat (HADD).

However, assessments of DFO's success in achieving the objective of its Habitat Policy have been limited since the policy's adoption in 1986. Those evaluations completed, including a recent national review, have concluded that a net loss of productive capacity in Canada's fish habitats is likely occurring, but the true gains and losses of habitat have been difficult to gauge without a clear structure for assessment that includes suitable monitoring methods.

To assess the effectiveness of compensation and stewardship projects at project, regional and national scales, a coherent strategy is required. The foundation of this structure is timely, consistent and rigorous project monitoring.

PURPOSE OF DOCUMENT

This document presents monitoring and assessment guidance for fish habitat compensation and stewardship projects. It is intended to be a resource for managers and project proponents engaged in monitoring and assessment work. The methods and approaches presented are flexible enough to accommodate a wide range of project sizes and complexities and to accommodate regional variation, but impose sufficient scientific rigour and standardization of methods to ensure that success can be assessed at the project, regional, and national scales. Four case studies covering both marine and freshwater environments are used to illustrate the methods presented.

CHALLENGES

Designing monitoring schemes that are both workable and capable of generating results useful for evaluating management decisions is a challenge. Considerations include choosing an appropriate experimental design, choosing the appropriate scales for monitoring, identifying factors limiting production in target populations (bottlenecks), controlling for effects of fish movement, recognizing the difficulties in measuring the productive capacity of habitat (the basis of no-net-loss determinations), avoiding cumulative impacts, dealing with tradeoffs among species, and the potential for bias when the same parties design, build and monitor projects. These are discussed in chapter 3.

THE MONITORING STRATEGY

The structure presented in this document consists of three levels: routine monitoring for small projects that pose little risk to the resource, site effectiveness monitoring which is much more detailed and quantitative for large and/or higher risk projects, and program effectiveness evaluation to assess performance at the regional and national scales. Each is described briefly in the following sections.

The most important principles outlined in this guidebook (establishing measurable objectives, reference and control sites, replication, and pre-impact information) are the key elements upon which to focus any monitoring program.

In addition, a monitoring strategy should also take into consideration the points below:

- Monitoring should occur on scales both larger and smaller than the project was implemented on.
- Monitoring duration should be linked to rates of habitat change and life cycle duration of target species (minimum two life cycles).
- Pre-project planning should include assessment of watershed scale bottlenecks for target species.
- Decisions about tradeoffs between target species should be based on production estimates at a common life-history stage using a formal decision analysis framework.
- Project monitoring in settled landscapes should include a sociological impact assessment.

Routine Monitoring

Routine monitoring focuses on project integrity, compliance with approved design, and subjective indicators of success, and includes a sociological component in settled areas. It employs a variety of physical and biotic variables and indices to construct a composite analysis of habitat productive capacity. Routine monitoring should be regarded as a basic program, necessary for all projects and should use methods compatible with those of site effectiveness monitoring to facilitate project comparisons. Its methods are intended to be usable by people with a small to moderate amount of field training. Protocols require less time and technical expertise than site effectiveness monitoring methods, but still provide participants and managers with valuable data for project and program evaluation. The level of detail required will depend upon the size of the project and the risk level associated with it (e.g. for simple small-scale projects fewer variables would be measured and post project monitoring duration would be shortened). Routine monitoring should provide the information necessary to fulfill three objectives:

1. To verify that the project was implemented as designed and approved.
2. To determine if the project is biologically effective.
3. To document how the project is perceived in the community.

Routine monitoring should consider the following points:

- Evaluate a variety of physical and non-fish biotic variables and indicators to provide a more complete and mechanistic picture of changes in natural productive capacity of habitats.
- Existing and newly developed Streamkeeper, Wetlandkeeper and Shorekeeper methods and protocols should be used when possible.
- Additional advanced training opportunities and outreach should be developed for proponents and community groups (e.g. Streamkeepers, Wetlandkeepers, and Shorekeepers).
- Monitoring programs should include time series photography from standardized viewpoints.
- Regionally standard data sheets and reporting formats for routine monitoring including example opinion surveys.
- The adoption of more rigorous site effectiveness monitoring methods when interest and/or resources are available.
- Pre-project monitoring periods (two or more years) and post project monitoring staggered over 10 years or more.
- The inclusion of monitoring funding as a standard part of granting packages for federally funded stewardship projects and monitoring program criteria should be considered in project selection processes.

See Table 2 for a summary of the recommended methods to achieve each objective. Rationales and discussion are provided in chapter 4.

Site Effectiveness Monitoring

Site effectiveness monitoring should be viewed as an expansion of routine monitoring. It will include all routine monitoring variables in addition to a number of more expensive or technically demanding measurements. The most important difference, however, is in the application of quantitative experimental design and statistical analysis. Detailed reviews of these topics are provided in chapter 5. Site effectiveness monitoring should be applied to all large and/or complex compensation and stewardship projects and to those judged to pose a significant risk to the resource. The objectives of site-effectiveness monitoring are similar to those of routine monitoring with the exception that measures of biological effectiveness are quantified in terms of net gain or loss of productive capacity. They are:

1. To verify that the project was implemented as designed and approved.
2. To quantify the net change in habitat productive capacity.
3. To document how the project affected social values in the community.

The following points should be considered in site effectiveness monitoring:

- Paired Before-After Control-Impact (BACIP) experimental designs should be used for larger or more complex compensation and stewardship projects. Ideally, each should have two independent control sites and, if mobile species are involved, an additional 'local' control site.
- Whenever possible, pre-project monitoring periods of two or more years should be used and post project monitoring should occur over 10 or more years in two-year pulses.
- Monitoring frequency should ideally be a minimum of three times per year for variables suitable for BACIP analysis.
- Statistical power of tests and the relative risks of type I and type II errors should be considered and reported *a priori* for all sampling designs.
- Calibrated multi-metric indices of biotic integrity should be developed for each region and be used in no-net-loss of habitat productive capacity (NNL) assessments.

See Table 5 for a summary of methods recommended for achieving each objective. Rationales and discussion are provided in chapter 5.

Program Effectiveness Evaluation

Program effectiveness evaluation focuses on the effectiveness of different management approaches or strategies in achieving management objectives. Program effectiveness evaluation depends upon the collection of consistent, comparable data from routine and site effectiveness project monitoring. The results of many project level assessments are combined, statistically assessed and compared, allowing managers to rigorously evaluate techniques (e.g. new habitat compensation and stewardship strategies) and management approaches. Program effectiveness evaluation provides critical information for adaptive management. Regional and/or national management of these evaluations would occur through coordination, training, and standardization of monitoring methods.

In practical terms program effectiveness evaluation requires the establishment of coordinated regional and/or national analysis and interpretation of monitoring information to determine how management approaches are functioning and where improvements can be made. The data generated would facilitate adaptive management by enabling evaluation of how well the methods used in projects are achieving overall management objectives (e.g. track achievement of NNL, compliance trends at regional and national scales, etc.).

Outlined below are the main points to consider in program effectiveness evaluation:

- Regions should develop habitat specific lists of monitoring variables required and adopt standard measurement methodologies to facilitate program effectiveness evaluation.

- Similar projects in similar habitats should be incorporated into active adaptive management experiments to evaluate the effectiveness of different management practices.
- Monitoring data should be coordinated to track gains and losses in habitat, and to facilitate compilation of results for program effectiveness monitoring.

Program effectiveness evaluation is discussed in detail in chapter 6.

A STRATEGY FOR ADAPTIVE MANAGEMENT

Routine and site effectiveness monitoring can be used in a nested fashion through program effectiveness evaluation to facilitate adaptive management (see Figure 1). Routine monitoring is used primarily to fine tune project implementation. Site effectiveness monitoring is used to ensure that a project is meeting quantitative design objectives. Both of these occur at the project scale and are the responsibility of project proponents. In contrast, program effectiveness evaluation is used to study how well the methods used in projects are achieving overall management objectives. It encompasses many projects and allows managers to statistically assess and compare results from different types of projects and to rigorously test new practices and management approaches.

1. INTRODUCTION

Very few habitat compensation and stewardship projects are adequately monitored and evaluated (Bradshaw 1993, Kondolf and Micheli 1995, Frissell and Ralph 1998, Smokorowski et al. 1998, Levings 2000). The consequences of insufficient monitoring prevents us from recognizing breakthroughs and mistakes, while inappropriate monitoring wastes scarce resources on collecting data that cannot be applied. Optimal monitoring effort depends on a project's risks, goals, and consequences of failure. It also depends upon what is already known about the methods employed (MacGregor et al. 2002).

By applying principles of good scientific design (explicit hypotheses, controls, replication, etc.) to monitoring we can achieve many of the benefits of an experimental approach. Primary among these are a rapid learning curve and a known level of confidence in estimates of the effects of policies or practices. Adaptive management is when these policies or practices are then adjusted accordingly to increase the chance of successfully achieving objectives. In a particularly promising approach, *active adaptive management*, available data is used to explicitly evaluate and compare alternate management strategies and/or approaches. Policies or practices are then chosen to maximize expected value considering the costs and benefits of learning (Walters and Holling 1990).

To counter the ever-increasing impacts of anthropogenic activities on fish habitat, Fisheries and Oceans Canada (DFO) implemented its Habitat Policy (DFO 1986) with the guiding principle of no net loss (NNL) in productive capacity of fish habitat in Canada. Under the policy, productive capacity lost to harmful alteration, disruption, or destruction of habitat (HADD) is compensated for through proponent funded creation, restoration or enhancement of other fish habitats. The Habitat Policy, the cornerstone of DFO's fish habitat management program, states that DFO's long-term objective is "the achievement of an overall net gain (NG) of the productive capacity of fish habitats." Achievement of this objective is to be attained by meeting three goals: 1) conservation of fish habitat through the implementation of the Habitat Policy's guiding principle of NNL; 2) restoration of damaged fish habitat; and 3) creation of new fish habitat. This document presents a multi-level monitoring and assessment strategy that would allow rigorous evaluation of the success of fish habitat projects, as well as evaluation of the achievement of these Habitat Policy goals.

To achieve the conservation goal of the Habitat Policy, the NNL principle is applied when DFO issues an authorization under Section 35 of the *Fisheries Act* for a HADD typically resulting from some sort of development activity. In applying the NNL principle, DFO requires the proponent, as a condition of authorization, to balance unavoidable losses in the productive capacity of fish habitat through habitat compensation. To achieve the restoration and creation goals of the Habitat Policy, DFO, other federal and provincial agencies, non-profit organizations, volunteer groups, and industry undertake stewardship projects to rehabilitate damaged habitats and create new habitats to achieve an overall net gain in the productive capacity of fish habitat. Stewardship projects also have an added social benefit as they can be used to promote public awareness of the importance of fish habitats and can instil positive attitudes and local pride in the fisheries resource.

Since the implementation of the Habitat Policy, thousands of compensation and stewardship projects have been undertaken across Canada (DFO 2002a). However, while the Habitat Policy "provides objective statements against which the Department can measure its performance in fish habitat management" (DFO 1986), few evaluations of DFO's performance in achieving goals of the Habitat Policy have been conducted (Kistritz 1996, Cudmore-Vokey et al. 2000, Minns and Moore 2003, Harper and Quigley 2005, Quigley and Harper 2005b). Furthermore, the majority of monitoring and evaluations that have occurred have been short term (1-3 years), judgement based and qualitative rather than quantitative (Quigley and Harper 2005a), and have included selection of inadequate performance criteria, lack of proper baseline information prior to project implementation, and have failed to employ reference sites for comparative purposes (Harper and Quigley 2005). Most studies have based their NNL determinations simply upon area gained or lost rather than scientifically defensible assessments of the true productive capacity of fish habitats.

This document discusses the many challenges inherent to monitoring compensation and stewardship projects and describes two types of project-level monitoring: routine monitoring and site effectiveness monitoring. Routine monitoring is less quantitative in nature and is intended for small compensation and stewardship projects with low risk of adverse impacts to the resource and for practitioners with a small to moderate amount of field training. Site effectiveness monitoring employs a quantitative experimental design and statistical analysis and should be utilized when assessing the effectiveness of larger and/or more complex projects in achieving NNL or a NG in habitat productive capacity. Case studies illustrating the proper use of effectiveness monitoring in different habitat types are presented for two types of compensation projects (like and unlike). An example of routine monitoring is provided for a stewardship project. We also present a proposed methodology for program effectiveness evaluation based on active adaptive management. This program effectiveness evaluation, through coordinated regional and/or national analysis and interpretation of monitoring information, can determine how management approaches are functioning and where improvements can be made. This would allow specific recommendations for future policy and program adjustment and development.

2. DEFINITIONS AND OVERVIEW

2.1 TYPES OF PROJECTS

DFO leads or reviews most fish habitat projects in Canada. It also funds a significant number of projects. We divide fish habitat projects into two categories: compensation projects and stewardship projects. Both are undertaken to ensure that the achievement of an overall NG of the productive capacity of fish habitats is realized, and both can be used to promote public awareness of the importance of fish habitats. They differ primarily in that compensation projects are undertaken to balance an unavoidable loss in fish habitat productive capacity as a result of a HADD.

2.1.1 Compensation Projects

Compensation projects are required in conjunction with issuance of an authorization under Section 35 of the *Fisheries Act* to offset a HADD. The proponent is typically required to compensate for the habitat losses according to DFO's hierarchy of preferences (DFO 1986, 1998, 2002a).

To increase the probability that NNL will be achieved, DFO often requires proponents to create or restore more habitat than was lost as a result of the HADD due to the uncertainty of success of habitat compensation, the variability in the quality of the fish habitat being replaced, and recognition of the lag time required for the compensatory habitat to become ecologically functional (DFO 2002b). This results in a compensation ratio (compensation area:HADD area) that is greater than 1:1. The proponent may be required to conduct follow-up monitoring to determine the effectiveness of the mitigation and compensation measures taken to conserve the productive capacity of fish habitat. This monitoring can be used to gauge project success as well as DFO's performance in achieving its conservation goal of NNL.

2.1.2 Stewardship Projects

Stewardship projects are undertaken by DFO, other federal and provincial agencies, non-profit organizations, volunteer groups, industry, acting alone or in partnership with one another, to achieve the restoration and creation goals of the Habitat Policy and to achieve an overall NG. They include the rehabilitation of damaged habitats and creation of new habitats to assist in the recovery of an existing ecosystem that has been degraded, damaged or destroyed. While not required, post-construction monitoring of stewardship projects to evaluate their success in achieving the desired objectives is often conducted by the practitioner. This monitoring can also be used to gauge project success and DFO's performance in achieving the restoration and creation goals of the Habitat Policy and an overall NG.

2.2 TYPES OF MONITORING

Compensation and stewardship projects differ in their risk to fish habitat and in the resources and responsibilities of their proponents. Compensation projects, by definition, are linked to a HADD of fish habitat and therefore if they fail to achieve their objectives, net loss of fish habitat results. As a consequence, these projects inherently pose high risks to fish habitat. Costs for the construction of the compensatory habitat and the monitoring and reporting requirements are assumed by the proponent. Stewardship projects include the rehabilitation/restoration of damaged habitats and the creation of new habitats. A failure of a stewardship project is less likely to result in a net loss of fish habitat. As a result, stewardship projects generally pose minimal risk to fish habitat. Their low risk, limited regulatory review (with respect to the *Canadian Environmental Assessment Act* and the *Fisheries Act*) and funding constraints often result in less detailed monitoring, although they would typically benefit from increased effort. In this paper we identify three levels of monitoring.

2.2.1 Routine Monitoring

Routine monitoring focuses on project integrity, compliance with approved design, and subjective indicators of success, and should include a sociological component in settled areas. It employs a variety of physical and biotic variables and indices to construct a composite analysis of habitat productive capacity. Routine monitoring should be regarded as a basic program, necessary for all projects and should use methods compatible with those of site effectiveness monitoring to facilitate project comparisons. The level of detail required will depend upon the size of the project and the risk level associated with it.

Routine monitoring is primarily qualitative in nature. The boundary between qualitative and quantitative methods is blurred in that qualitative research often uses some quantification, although it is not seen as central to the analysis. In qualitative research the investigator constructs knowledge from indirect data sources rather than collecting and statistically interpreting numeric data (Mason 1996). The primary methods include simple measurements and surveys, interviewing, observation, and use of existing documents. Analyses are descriptive in nature, typically using text or simple graphical presentations (means, distributions, etc.).

2.2.2 Site Effectiveness Monitoring

Site effectiveness monitoring focuses on project integrity, compliance with approved design, and the achievement of habitat objectives (measured quantitatively), and should include a sociological component in settled areas. Site effectiveness monitoring should be applied to major and/or complex stewardship and compensation projects. Like routine monitoring, it employs a variety of physical and biotic variables and indices to construct a composite analysis of habitat productive capacity. It is both qualitative and quantitative, but emphasizes the latter. For our purposes, we will confine the definition of quantitative methods to those that use formal experimental designs to document the presence or absence of differences with known chances of error.

2.2.3 Program Effectiveness Evaluation

Program effectiveness evaluation focuses on the effectiveness of different project types, as well as management approaches and strategies, in achieving management objectives. Program effectiveness evaluation depends upon the collection of consistent, comparable data from the routine and site effectiveness monitoring of stewardship and compensation projects. The results of many project level assessments are combined, statistically assessed and compared, allowing managers to rigorously evaluate new habitat compensation and stewardship techniques and management approaches. Program effectiveness monitoring and evaluation provides critical information for adaptive management.

2.3 ADAPTIVE MANAGEMENT IN PROGRAM MONITORING

Management policies or strategies can be viewed as experiments with highly uncertain outcomes (Walters and Holling 1990). By applying good scientific design to these experiments we can increase the rate at which we learn. In particular, we can estimate, with a known level of confidence, some of the effects and consequences that management decisions are having, and adjust them accordingly to improve the chance of successfully achieving objectives. The term for this approach is adaptive management. In its most effective form, *active adaptive management*, two or more alternate approaches are applied to the same problem, their effects measured, and results compared. Policy is chosen to maximize the expected value of its outcome (i.e. choosing the most effective policy) including consideration of the costs and benefits of learning (Walters and Holling 1990). For example, coho salmon and cutthroat trout use off-channel ponds as refuge areas during periods of high flow. Such habitat is commonly created in stewardship and compensation projects in British Columbia, although optimal pond design (depth, size, morphology) remains unknown (Roni et al. 2002). Managers involved in program effectiveness evaluation could assign different designs to each of several groups of projects and compare their use by fish and impacts on fish populations. The information would be useful in refining designs of future projects, especially when combined with cost-benefit or decision analysis tools (see MacGregor et al. 2002 for example).

Adaptive management can be applied at any scale; however, the best studies are done at several scales so that what is learned on one project can be applied to others and to larger scale objectives. Experimental designs, in which smaller scale experiments are nested within larger scales, allow data to be used very efficiently for this purpose (Walters and Holling 1990).

Routine, site effectiveness and program effectiveness monitoring methods (sections 2.2.1 to 2.2.3) could be used in a nested fashion to facilitate adaptive management (Figure 1). Routine monitoring is used primarily to fine tune project implementation. Site effectiveness monitoring is used to ensure that a project is meeting quantitative design objectives. Both of these occur at the project scale and are the responsibility of project proponents. In contrast, program effectiveness evaluation is used to study how well the methods (i.e. management practices) used in projects are achieving overall management objectives. It encompasses many projects and allows managers to statistically assess and compare results from different types of projects and to rigorously test new techniques and management approaches in habitat stewardship and compensation, as well as other, practices.

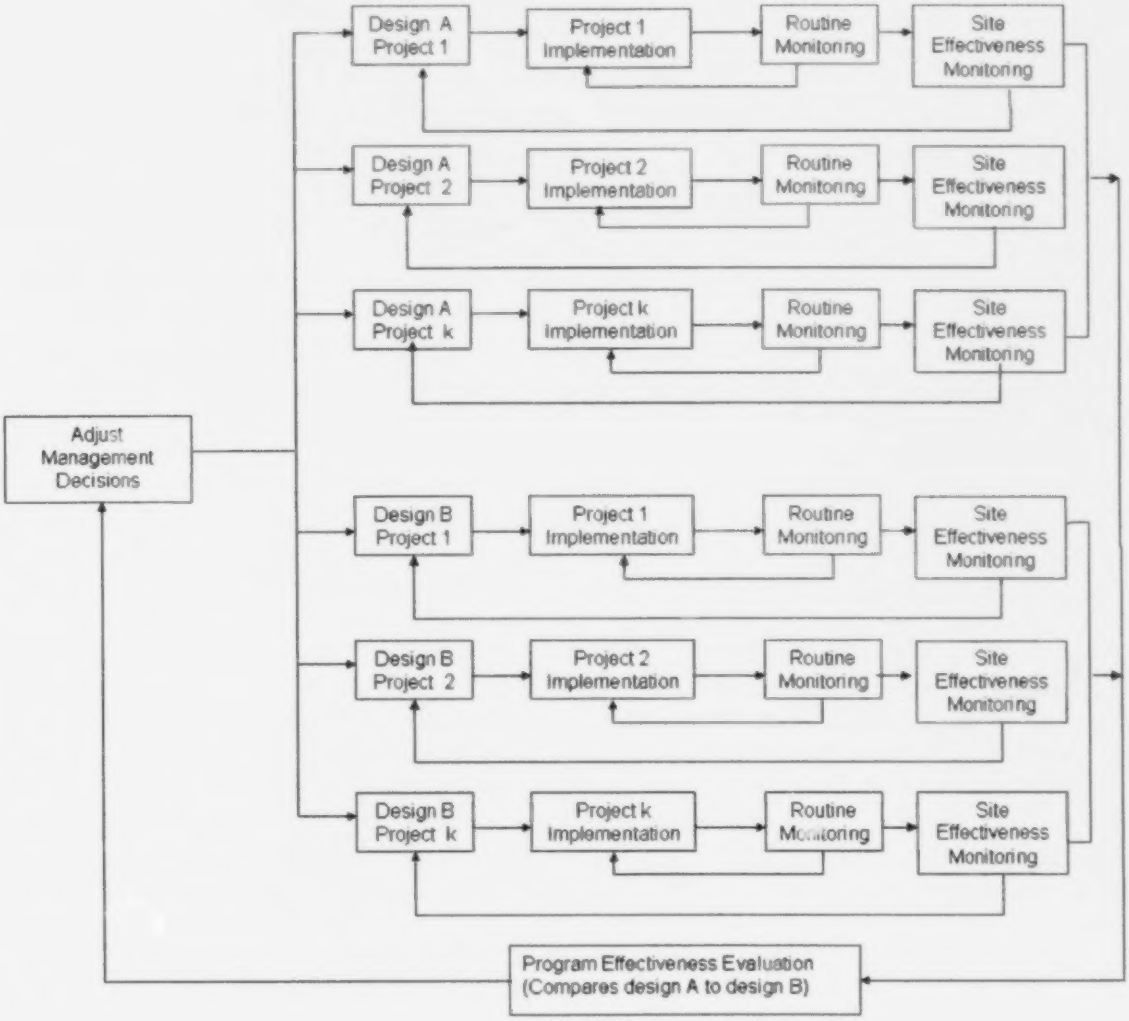
Design A Project 1
Project 1 Implementation
Routine Monitoring
Site Effectiveness Monitoring
Design A Project 2
Project 2 Implementation
Routine Monitoring
Site Effectiveness Monitoring
Design A Project k
Project k Implementation
Routine Monitoring
Site Effectiveness Monitoring
Adjust Management Decisions
Design B Project 1
Project 1 Implementation
Routine Monitoring
Site Effectiveness Monitoring
Design B Project 2
Project 2 Implementation
Routine Monitoring
Site Effectiveness Monitoring
Design B Project k
Project k Implementation
Routine Monitoring
Site Effectiveness Monitoring
Program Effectiveness Evaluation (Compares design A to design B)

Figure 1: A simple monitoring strategy for active adaptive management. The outer loop depends upon consistent monitoring methods among projects. Two project designs (A and B) and their effectiveness over multiple projects (1 to k) are compared in this example.

Nested monitoring requires that different projects use consistent methods of data collection and evaluating success. One of the major objectives of this paper is to promote such consistency so that large-scale adaptive management is possible regardless of what objectives and hypotheses at a given time happen to be. In section 6 we discuss program effectiveness evaluation designs in more depth.

3. CHALLENGES IN MONITORING

3.1 TEMPORAL AND SPATIAL SCALES

Identifying appropriate scales in assessment work is a critical feature of project planning that is well outlined by several authors (Imhof et al. 1996, Harris and Olson 1997, Kershner 1997, Roni et al. 2002). When a project is implemented or monitored without considering large-scale events and processes (e.g. floods, droughts, species introductions, and cumulative impacts), problems including project failure may result (Frissell and Nawa 1992, Avery 1996, Lewis et al. 1996). Monitoring on smaller scales within the project is also important as measuring change at that level often sheds light on causes and mechanisms of impact.

As a general policy we recommend monitoring at a range of spatial scales both larger and smaller than that of project implementation. Temporal scales (frequency and duration) of monitoring should be linked to those of habitat development rates and the life cycle of target species.

3.2 PRODUCTION BOTTLENECKS

Production bottlenecks may control population size or individual growth through processes acting at scales ranging from reaches to regions (Reeves et al. 1991, Lewis et al. 1996). Examples of potential bottlenecks include lack of spawning or juvenile rearing habitat, high ocean mortality, or seasonally poor water quality in adult habitat. Fish production is the generation of tissue weight per unit area (biomass) per unit time (Anderson and Neumann 1996). It can be limited at any life history stage. Habitat projects relieving or addressing a bottleneck will likely result in an increase in fish production. However it must be recognized the situation is complicated by the fact that populations can be limited by more than one factor and by different factors in different years (Hartman et al. 1996, House 1996).

When a bottleneck occurs at an earlier life history stage than the one addressed by or monitored in a project, the population will fail to respond to the project. For example if a salmon population is limited by conditions on spawning grounds, population size is unlikely to increase in response to restoration of estuarine rearing habitat. Conversely, when bottlenecks occur after the life-stage monitored, a species may appear to respond strongly even though production at later life stages is unaffected (e.g. Murphy et al. 1986, Schlosser 1998).

To provide a more complete and mechanistic picture of changes in productive capacity, we advocate identifying and quantifying bottlenecks at the project design stage (Everest et al. 1991, Minns 1997) and monitoring physical habitat and non-fish biotic variables in conjunction with fish productivity.

3.3 FISH MOVEMENT AND MIGRATION

Fish movement between habitats breaks the link between local conditions and production. Most habitat project monitoring schemes, however, have assumed that changes in fish density or biomass within the project site reflect changes in habitat productivity there. Increases are taken as strong evidence of project success (e.g. Moore and Gregory 1988, Keeley et al. 1996, Cedarholm et al. 1997) but could simply be the result of immigration from nearby habitats (Frissell and Ralph 1998). Conversely, when projects do relieve production bottlenecks they can increase fish production over areas well beyond their boundaries (Gowan et al. 1994).

The effects of fish movement and migration on results can be quantified by increasing the area over which monitoring takes place (the spatial scale; section 5.4.1). We also strongly advocate measuring production of less mobile taxa (invertebrates, periphyton etc.) in addition to fish. These biota can often provide managers with more powerful indicators of changes in the productive capacity of local habitats (Quigley and Harper 2005b).

3.4 MEASURING PRODUCTIVE CAPACITY AND NO NET LOSS

Productive capacity is defined as "the maximum natural capability of habitats to produce healthy fish, safe for human consumption, or to support or produce aquatic organisms upon which fish depend" (DFO 1986). It is analogous to carrying capacity, which can be defined as the maximum biomass of organisms that can be sustained on a long-term basis by a given habitat (DFO 1998). Compensation projects are required to achieve NNL in the productive capacity of habitat. There are a number of practical difficulties in measuring productive capacity and NNL. These are outlined below.

3.4.1 Lack of Direct Measures

Productive capacity cannot be directly measured as it "is a potential vested in the habitat and independent of the extant stocks of fish or associated organisms" (Minns 1997). All monitored variables, including current fish production, are indirect measures and have an uncertain relationship to natural productive capacity.

To provide a more complete picture of habitat productive capacity upon which to base evaluations of project success and/or achievement of NNL, we recommend measuring a variety of physical and biotic variables including production of multiple taxa representing several trophic levels.

3.4.2 Tradeoffs Among Species

Habitat changes can alter fish communities by changing total biomass, by altering relative abundance, or by shifting the distribution of species or life stages in time and/or space (Minns et al. 1996). Of these, only a reduction in total biomass constitutes a net loss by definition, but a biomass-neutral shift in community composition in which a highly desired species was replaced by a less valued one (e.g. trout for carp) would be viewed by most as a lack of project success. This puts assessment of project success and the concept of no net loss on a highly subjective basis.

When habitat for two species of management concern must be traded off, managers can choose to optimize habitat work for one at the expense of the other or to compromise for a lesser benefit to both (section 5.4.9.3, Scruton 1996). Monitoring must extend beyond single species approaches to identify and evaluate these situations. Decision analysis methods can provide extremely useful guidance in approaching these problems (Walters and Holling 1990, MacGregor et al. 2002).

3.4.3 Cumulative Effects

It is quite possible to fully compensate for losses in productive capacity in each of 10 individual projects within a watershed yet still lose productive capacity at a watershed scale. This can happen if the spatial configuration of habitats needed at different life stages becomes less optimal, or if the total amount of a limiting habitat type is reduced through unlike compensation projects. Managers must consider these issues carefully in selecting or approving compensation sites. Assessment of watershed scale population bottlenecks and knowledge of movement and migration limits of different life stages of target species are needed to inform such decisions.

3.4.4 The Moving Target Problem

Habitat, and thus its productive capacity, is constantly changing. The rate of change is likely to be particularly fast in the recently constructed or manipulated habitats of compensation and stewardship project sites. The development trajectory of these sites is also likely to be non-linear and complex (Walters and Holling 1990, Zedler and Callaway 1999). Consequently, the presence and amount of net loss or net gain is likely to depend on when it is measured. The frequency and duration of sampling must be carefully designed to capture these changes (sections 4.7 and 5.4.6).

3.5 BIAS AND QUALITY ASSURANCE/QUALITY CONTROL

Frequently a single individual or consulting firm will be responsible for the design, implementation and evaluation of a project. Obviously this has potential to bias evaluations. The adoption of standardized study designs and sampling methods should help minimize problems, but careful scrutiny of methods, data and reports by managers will always be necessary. Additionally, independent monitoring of a subset of projects for quality assurance/quality control (by DFO or independent contractors) would be a valuable addition to program effectiveness monitoring.

3.6 SOCIOLOGICAL CONTEXT

3.6.1 Public Understanding of Issues

Increased public awareness of fish and fish habitat issues is likely to have general and widespread benefits for the environment (Geist and Galatowitsch 1999, Grese et al. 2000). Compensation and stewardship projects can provide substantial societal benefits in the form of public education. They can be used to promote public awareness of the importance of fish habitats and can instil positive attitudes and local pride in the fisheries resource and its habitat. Documenting the contribution of habitat projects to public understanding of conservation issues is important to understanding the full value of projects and should be part of monitoring programs.

3.6.2 Public Support

Projects that enjoy broad support locally are more likely to benefit from long-term stewardship from the community and to spawn additional opportunities for stewardship projects on private land. There is a tendency among proponents of habitat projects to believe that their work will be perceived as obviously beneficial by others (Vining et al. 2000), although this is sometimes not the case. Failure to acknowledge, monitor, or address local concerns has led individual projects and entire programs to fail (McClain and Lee 1996, Rhoads et al. 1999, Helford 2000).

A person's support or opposition to a habitat project is strongly influenced by the type and strength of attachment they have to the place in which it occurs. This attachment may be aesthetic or functional (Ryan 2000) and may be based on values very different from those of 'experts' involved in project development (Geist and Galatowitsch 1999). Project proponents and approval agencies need to know how habitat projects are perceived locally from early in the planning phase, so concerns can be addressed at the design stage, until well after the project is implemented so unforeseen issues can be addressed.

The *Canadian Environmental Assessment Act* (CEAA) contains measures to ensure that there are opportunities for timely and meaningful public participation throughout the environmental assessment process, which applies to most projects led, funded, or permitted by the federal government. When HADDs are authorized by DFO, for example, CEAA is triggered and an environmental assessment must be conducted, which requires that the public be given an opportunity to provide meaningful feedback. The effectiveness of the process must also be evaluated to ensure that the public's interests have been appropriately considered. While stewardship projects often do not trigger CEAA and provide opportunity for public participation, the level of public support should be gauged for each project when possible.

3.6.3 Volunteer Support

The success of many stewardship projects depends upon recruiting and gaining the long-term commitment of community volunteers whose roles may vary from participating in tree planting events to proposing and implementing projects. When adequately trained and supported, volunteers can provide quality monitoring data using complex methods (Penrose and Call 1995, Fore et al. 2001), although currently this capacity is rarely utilized to its full potential in Canada. Monitoring the commitment, motivations and satisfaction of volunteers can help identify strategies for recruiting new participants and retaining existing ones (Grese et al. 2000).

4. ROUTINE MONITORING

Routine monitoring should be regarded as a basic necessity for all projects. For those with low risk of adverse impacts to the resource it will typically be the only form of monitoring. Routine monitoring methods are intended to be usable by people with a small to moderate amount of field training. Protocols require less time and technical expertise than site effectiveness monitoring methods, but still provide participants and managers with valuable data for project and program evaluation. Routine monitoring should provide the information necessary to fulfill three objectives:

1. To verify that the project was implemented as designed and approved.
2. To determine if the project is biologically effective.
3. To document how the project is perceived in the community.

In the following sections we outline the basic components of a routine monitoring program using these objectives as a framework. We provide an overview of how and when to collect data on commonly used physical and biological variables, references for detailed methods, guidance on designing and administering public opinion surveys, and an outline of preferred data analysis and reporting methods. We do not supply data sheets or advocate a single monitoring protocol because projects vary far too widely in type and scope to permit such a cookbook approach. Managers familiar with regional priorities, constraints and species are best equipped to develop standardized routine monitoring methods that will facilitate program effectiveness evaluation. Case study 1 (see section 7.1) provides an example of a routine monitoring program for a project undertaken by a volunteer stewardship group.

4.1 OBJECTIVE 1: To verify that the project was implemented as designed and approved

4.1.1 What to measure

Area: Does the total area of habitat created or restored match that of the specifications of the approved design?

Configuration: Does the spatial arrangement of habitat types correspond to the approved design?

Materials: Are the materials used of the type and size specified in the approved design?

Structural integrity: Are all structures (e.g. inlets, outlets, riffles, rootwads, etc.) in place and functioning as designed? Is there significant structural instability (e.g. erosion) on the site?

4.1.2 How to measure it

4.1.2.1 As-Built Survey: Problems with project dimensions, habitat configuration, materials used, and structural integrity should be identified through explicit comparisons to design specifications in an as-built survey conducted within a year of project completion. Simplified topographic survey methods combined with a checklist for presence and integrity of important project elements should be used to facilitate these comparisons. Photographic monitoring of important project features (e.g. inlet structures) is also advised (see section 4.4.3).

In the topographic surveys, benchmark locations for distance and, if appropriate, elevation measurements should be established in a pre-project survey. In streams, bankfull width must be included as wetted width may vary greatly with discharge. Similarly marine and estuarine surveys must include tide levels at the time of survey relative to zero chart datum to permit comparisons of habitat areas over time. Guidance on survey methods suitable for routine monitoring is available in the Streamkeepers Handbook (Taccogna and Munro 1995), the Wetlandkeepers Handbook (Southam and Curran 1996) and the Shorekeepers handbook (Jamieson et al. 1999).

4.1.2.2 Follow-up Surveys: As habitat changes over time, additional post-project surveys are recommended in the second, fifth and tenth year following construction. Informal visual inspections of structural integrity should be conducted annually and following all major natural disturbances (e.g. large floods, major storm events).

4.2 OBJECTIVE 2: To determine if the project is biologically effective

Most projects will have one or a few target species which are of primary interest because they are economically important, are listed as endangered or vulnerable or are considered keystone species upon which habitat integrity depends (e.g. eelgrass). Changes in their populations, although important to managers, are often difficult to measure for reasons of rarity or high natural variation (Osenberg et al. 1994, Minns et al. 1996). Monitoring supplementary physical and biotic variables thought to be related to the capacity of habitat to support these species is particularly important in these cases. Ideally, those variables chosen will be easy to measure, show rapid response to habitat changes, and be relatively immobile. Examples include measures of periphyton, macro-invertebrate, and macrophyte density. In many cases these variables will represent the ability of a habitat to support fish more accurately than current fish densities, which may depend upon fishing pressure, ocean conditions or other production bottlenecks.

4.2.1 What to measure

In the following section we discuss the most common categories of variables used to assess project effectiveness in routine monitoring. The specific variables and methods for measuring them will vary greatly between regions and types of projects.

4.2.1.1 Presence and density of fish species: The most basic piece of information regarding a project's success is documentation of habitat use by fish species. Beyond this, changes in density (abundance per unit area) can be assessed without estimating population size using indirect methods. Catch-per-unit-effort (CPUE; e.g. average number of fish/trap/day), and site coverage data (e.g. percent area in eelgrass) are common examples. They are easy to use, will often identify changes in relative abundance and with standardized methodology are comparable between projects. Success depends upon selecting the appropriate sampling method(s) for the target species and upon expending sufficient effort to obtain reasonably precise estimates.

4.2.1.2 Presence and density of other organisms: Using the presence and density of other species and groups of organisms as indicators of habitat quality is a very useful approach. This data provides information that helps explain trends in target species populations, and is especially useful when fish species are rare or difficult to sample precisely. For example, non-target fish species are often important predators, competitors or forage species of fish species, and other measures (e.g. invertebrates, periphyton, macrophytes and riparian vegetation, water quality parameters, etc.) give indications of habitat quality.

Benthic macroinvertebrates are used extensively in freshwater assessment work (Rosenberg and Resh 1993). Their community structure (type and relative abundance of species) is very responsive to changes in water quality and some physical habitat features (e.g. substrate type). Various indices of community structure have been developed, although most require considerable taxonomic skills to apply (Karr 1998). Simplified methods for use by volunteers typically use family-level identifications. While these are useful in screening for problems, they can have poor resolution on the extremes of habitat quality. A challenge is that the quality of healthy sites tends to be underestimated (as the rare taxa that distinguish them are missed) while the quality of extremely degraded sites is overestimated (Penrose and Call 1995). However, the Canadian Aquatic Biomonitoring Network (CABIN) sponsored by Environment Canada is a good example of a common bioassessment approach with standardized protocols. It uses the reference condition approach (Reynoldson et al. 1997) to determine whether differences in organisms between reference sites and test sites indicate any impairment at the test site. For routine monitoring we recommend methods based on the Streamkeepers Program (Taccogna and Munro 1995) or CABIN (Environment Canada 2004). More rigorous methods are suitable for interested, well trained volunteers (Penrose and Call 1995) and are discussed briefly under site effectiveness monitoring (section 5.2.1.3).

Increasingly, periphyton (attached algae and associated organisms) are being used in a similar fashion to benthic macro-invertebrates in bioassessment work. Identification of periphyton species is time consuming and requires specialized training, but for routine monitoring purposes simple indices of density are sufficient. Barbour et al (1999) present an excellent method of measuring periphyton coverage that is described in case study 1 (see section 7.1.6.4).

Macrophytes and riparian vegetation may provide cover, food, and/or spawning substrate for target species. They also contribute to water quality and temperature moderation. For routine monitoring purposes simple measures of coverage (e.g. percent area) and/or average stem density are adequate.

4.2.1.3 Water Quality and Temperature: A wide range of water quality parameters might be of interest, depending on the project. Some of the more commonly monitored factors are dissolved oxygen, salinity, nitrate, phosphorous, ammonia, pH, and suspended sediment. Often they will be monitored only when the risk of a problem is thought to be significant at the design stage or when trying to identify sources of problems found after construction (e.g. eutrophication, fish kills, low productivity). Temperature extremes may limit habitat use of many species at least seasonally. Modern data logger technology makes monitoring temperature easy and inexpensive although hand thermometer readings of extreme values can still provide important information. Both temperature and water quality are of particular concern in habitats with limited natural flushing from stream flow or tides.

4.2.1.4 Other Physical Variables: Depending on the habitat type a wide range of other physical variables may be of interest. These include stream discharge and current velocity, tidal range, and abundance of cover.

4.2.2 How to measure it

Excellent handbooks and training courses in methods designed for volunteer stewardship groups are available through the Streamkeepers (http://www.pskf.ca/index.html), Wetlandkeepers (http://www.bcwf.bc.ca) and Shorekeepers (http://www.mvihes.bc.ca/shorekeepers) programs, as well as the CABIN program (http://cabin.cciw.ca/cabin). We recommend their procedures be adopted where possible. Their handbooks and a number of other useful methodological references are given in Table 1. References for more advanced methods are given in Table 3 (section 5.2.2).

Table 1: References for methods commonly use in routine monitoring protocols.

Topic	Reference	Notes
Biota and habitat	(Taccogna and Munro 1995)	Streamkeepers Manual
	(Southam and Curran 1996)	Wetlandkeepers Manual
	(Jamieson et al. 1999)	Shorekeepers Manual
	(Hauer and Lamberti 1996)	Streams
	(Barbour et al. 1999)	Streams and rivers
	(Environment Canada 2004)	CABIN Manual
Habitat Surveys	(Bain and Stevenson 1999)	Freshwater habitats
	(Kondolf and Micheli 1995)	Streams

4.3 OBJECTIVE 3: To document how the project affected social values in the community

4.3.1 What to measure

Measuring public opinion (through opinion surveys) should be the core of routine sociological monitoring but be supplemented by documenting other indicators of success. These might include incidences of vandalism, changes in public use of sites (e.g. number of anglers on weekend mornings in June), levels of volunteer participation, and attendance by political figures at project events. The amount and tone of media coverage and letters to the editor are also useful indicators, but are biased in that they are often more likely to identify problems than successes.

4.3.2 How to measure it

Simple questionnaires are the recommended method of monitoring a project's social impacts. If properly designed and analyzed they will reveal a great deal about the knowledge and attitudes of different groups of stakeholders. They can also be excellent vehicles for volunteer recruitment and identifying available resources in the community. Survey length and the effort expended in delivering it should be scaled to the size and the project's potential for controversy. For even the smallest projects, however, neighbours should be informed and asked about their opinions.

Some key considerations in designing and delivering surveys are (adapted from Jolliffe 1986):

- Ensuring that anonymity of response is possible, especially when controversy is anticipated.
- Including questions that will expose a respondent's knowledge of the issues as well as opinions of them.
- Ensuring that questions are posed in the same order and in the same manner to all respondents

- Inclusion of both open ended and closed questions. The former tend to provide more information, while the latter lend themselves to numeric description and quantitative analysis

The survey can be given by telephone or mail, but door-to-door contact of site neighbours and surveys of site users (e.g. dog walkers, cyclists) are generally better approaches. Walking tours and public information/comment sessions are excellent venues for giving surveys, and receiving other forms of feedback. These events provide the public an opportunity to interact directly with project designers and agency staff, but tend to be poorly attended unless controversy has already erupted or people have been personally invited to attend (Gobster and Barro 2000). We recommend them as a follow-up to an initial phone call or (better) door-to-door survey. Jolliffe (1986) provides an excellent overview of survey design and delivery as does the Statistics Canada web site (http://www.statcan.ca). Question design is discussed in depth by Kalton and Schuman (1982). An example survey is provided in case study 1 (see section 7.1.6.1 and 7.1.9).

4.4 DATA COLLECTION FORMATS

4.4.1 Field Notes

Field notes describing weather, general site conditions, wildlife observed or people encountered often turn out to hold key dates or information that clarifies other data. These notes, although seldom used directly in monitoring reports or analyses, are a critical component of monitoring records.

4.4.2 Checklists and Data Forms

Using data forms and checklists ensures that everything of importance is recorded on each visit in a consistent manner. In addition to space for data, they should include fields for the date and time of sampling, names of field crew members, a simple site map, and units of measurement for each variable.

Most variables in routine monitoring can and should be described in numeric terms for increased precision and easier use in quantitative analysis if desired. These include direct measurements, estimates of percentage, and graded subjective scales (indices). Presence/absence is also frequently used as an indicator. For example, the presence of gullying may be used as an indicator of erosion problems (Gaboury and Wong 1999) or the presence of a target species could be used as a simple indicator of success. Similarly subjective rating scales (e.g. 1-5) are routinely used to describe variables such as cover density (Gaboury and Wong 1999) and substrate size (Cummins 1962). The critical factor in developing and using indices and indicators is consistency. Each level of the scale needs to be explicitly described. When more than one person will be collecting data, it is advisable to compare their independent assessments of the same sample of cases to ensure consistency. A potential drawback of using rating scales is that each monitoring program will develop different systems that cannot be readily compared at the program monitoring level (see section 2.2.3). We recommend avoiding their use where possible, and consulting regional DFO staff when they are used to ensure data compatibility between projects. Preference should be given to methods published in the primary literature.

4.4.3 Photographic Monitoring

Photography should be part of all monitoring programs. It is inexpensive, quickly and easily accomplished, and provides an irreplaceable record that serves multiple purposes (e.g. illustrating reports and presentations, recording vegetation development). While ad hoc photographs of sampling procedures, wildlife use and habitat are important, photographic records are most effective when they include time series taken from standardized viewpoints. These provide clear records of site development over time and, with appropriate calibration, can be used to quantify habitat development (e.g. Van Horn and Horn 1996). Both site overviews and views of particular structures, plantings, or habitats of importance need to be included. Viewpoints should be standardized either with respect to existing landmarks or by installation of permanent markers (Van Horn and Horn 1996).

4.5 DATA ANALYSIS AND REPORTING

Reports summarizing results and recommending remedial actions should be prepared in both hardcopy and electronic formats for each year of monitoring. They should include a brief summary of project rationale, history, objectives and location (including UTM coordinates) in addition to descriptions of sampling methods and references to related reports and studies. Copies of checklists, data sheets and photographs should be added as appendices. The data should be clearly summarized in a 'results' section using a few simple statistics (e.g. total, percentage, mean, range, median, sample size) and perhaps a frequency histogram or simple table for each variable. For example, site survey results might reveal that a site has a total of 173 m^2 of pool habitat consisting of five pools with a median size of 21 m^2 and that 12 minnow traps yielded 25 rainbow trout with a mean length of 102 mm. A brief discussion of the results highlighting observed changes and trends relative to previous monitoring periods, and listing any recommendations should follow.

4.6 REFERENCE SITES

Levels of all of the variables measured will change over time due to large-scale external forces (succession, climate variability and change, etc.), even if a project has no impact whatsoever. The effects of a project can be separated from these by comparing values between the project site and other sites that are similar in character and are influenced by the same external forces, but not by the project. In formal scientific experiments these are referred to as control sites and are a key component for statistical analyses of results. In routine monitoring we refer to them as reference sites as their use is limited to comparisons of values and trends.

All routine monitoring programs should include at least one reference site. Like a control site, it should be similar in character to the project site but far enough away to prevent the project from influencing it. If resources permit, a second distant reference site can be added as insurance in case the first proves unsuitable for some reason. Addition of a local reference site (i.e. one immediately adjacent to the project site) is also beneficial when mobile organisms like fish are being monitored as it permits the effects of movement and migration on results to be identified (see section 5.4.1 for a detailed discussion).

4.7 FREQUENCY AND DURATION OF ROUTINE MONITORING

Monitoring is expensive in terms of both time and (usually) dollars. For routine monitoring, we recommend that all variables be measured in the year prior to project construction (two years is preferable) so that changes from this baseline state can be assessed. At minimum we recommend that post-project habitat monitoring be conducted once per year at 1, 2, 5 and 10 years following construction and after major flood or storm events (return periods of 10 years or greater). Seasonal monitoring and/or monitoring in more years (especially of biotic variables) is very valuable, as it improves information on variation within and among years. Post project opinion surveys at 1, 5 and 10 years will be adequate in most situations.

4.8 SUMMARY OF ROUTINE MONITORING

Table 2: Summary of design objectives and methods for routine monitoring.

	Description	Section
Objective 1	***To verify that the project was implemented as designed and approved***	4.1
As-Built Survey	• Compare project area (by habitat type), configuration, and materials to approved design. • Assess structural integrity. • Use simplified survey methods and photography from standard viewpoints	4.2.1-4.2.2 4.4.3
Follow-up Surveys	• Recommended for second, fifth and tenth years following project construction	4.2.2
Objective 2	***To determine if the project is biologically effective***	4.2
Approach	• Assessment of multiple variables to provide a comprehensive picture of habitat productive capacity. Measures of physical habitat, biological production at a range of trophic levels, and individual measures of fitness (e.g. fish growth and condition) should be included	4.2
Typical Variables	• Presence and catch-per-unit-effort of fish species • Macroinvertebrate density and diversity • Periphyton coverage • Riparian vegetation density and percent coverage • Dissolved oxygen • Water temperature	4.2.1-4.2.2
Monitoring Duration	• Usually one year of pre-project monitoring (two preferred) • Post-project monitoring in years 1, 2, 5 and 10	4.7
Monitoring Frequency	• At least once per year in monitoring years, seasonal is preferred if possible	4.7
Reference Sites	• One local and two distant reference sites preferred (one distant at minimum)	4.6
Data Analysis	• Numeric description where possible • Summary tables and graphs	4.5
Objective 3	***To document how the project affected social values in the community***	4.3
Study Design	• Opinion survey questionnaires	4.3.1-4.3.2
Data Analysis	• Numeric description • Summary tables and graphs	4.5

5. SITE EFFECTIVENESS MONITORING

The objectives of site-effectiveness monitoring are similar to those of routine monitoring with the exception that measures of biological effectiveness are quantified, usually in terms of net gain or loss. The objectives are:

1. To verify that the project was implemented as designed and approved.
2. To quantify the net change in habitat productive capacity.
3. To document how the project affected social values in the community.

Site effectiveness monitoring should be viewed as an expansion of routine monitoring. It will include all routine monitoring variables in addition to a number of more expensive or technically demanding measurements. The most important difference, however, is in the application of quantitative experimental design and statistical analysis. Site effectiveness monitoring should be applied to all large and/or complex compensation and stewardship projects and to those judged to pose a significant risk to the resource.

In the following sections we outline changes and additions to variables included in routine monitoring, describe some basic features of good experimental design, and discuss the preferred designs for different types of habitat projects. Case studies with example monitoring programs to illustrate methods for like (section 7.2) and unlike (section 7.3) compensation projects are provided later in this document.

5.1 OBJECTIVE 1: To verify that the project was implemented as designed and approved

5.1.1 What to measure

Site effectiveness monitoring of project compliance with approved designs includes the same variables (area, configuration, materials, integrity) as routine monitoring protocol (section 4.1), but more rigorous methods are used.

5.1.2 How to measure it

As-built and subsequent post-project surveys, as recommended for routine monitoring, are required in site effectiveness monitoring. Surveys must be conducted to permit precise area calculations. These surveys are particularly important in compensation projects where the ratio of the compensation area to HADD area is used in NNL calculations. Detailed survey methods for streams are provided by Kondolf & Micheli (1995) and Newbury & Gaboury (1993), while methods for subtidal areas are reviewed by Robinson et al (1996) and those for estuarine habitats are detailed by Hunter et al (1983) and by Williams (1993). Photographic monitoring from standard viewpoints is also recommended.

5.2 OBJECTIVE 2: To quantify the net change in habitat productive capacity

There are two aspects to determining net change in habitat productive capacity: the overall area of change (the amount of habitat created and/or affected) and for any particular variable the magnitude of change per unit area. This allows an evaluation of both habitat quantity and habitat quality (Minns 1995). Assessment of project success (e.g. NNL or NG of habitat productive capacity) requires the same multi-metric approach outlined for routine monitoring (section 4.2); however, more variables are measured in site effectiveness monitoring and more rigorous techniques are applied. In addition, measurements are made within the framework of a formal experimental design (section 5.4) and data is analyzed statistically (section 5.5).

5.2.1 What to measure

5.2.1.1 Abundance, Density and Production: Biomass is a measure of tissue weight per unit area, and production is the generation of tissue weight per unit area per unit time (Anderson and Neumann 1996). Each may calculated for a species (e.g. $g/m^2/year$ of trout), a higher level taxonomic group, a guild, a trophic level (e.g. g/m^2 periphyton), or a life stage and are regarded as a better index of habitat quality than simple abundance (Van Horne 1983, Minns et al. 1996). Production estimates often rest on estimates of density (abundance per unit area). Abundance should be measured using appropriate standard methods (e.g. quadrat counts, mark-recapture methods; Krebs 1989, Murphy and Willis 1996). More easily measured indirect indices (e.g. catch per unit effort, transect counts) can be used following calibration to direct estimators of abundance.

In target species, production is always of central interest, particularly in compensation projects which must demonstrate NNL of habitat productive capacity. Direct estimates of production (e.g. salmon smolt emigration, biomass accumulation) should be made, although this is difficult to do with acceptable precision in many target species. Periphyton, benthic macroinvertebrates, and macrophytes play important roles in food production and (in the case of macrophytes) cover for fish. Their standing biomass and production rates will frequently prove better measures of habitat productive capacity than will fish production itself. To assess NL or NG, estimates of abundance, density and/or production must be combined with the measurements of habitat area to take into account the compensation ratio (see section 5.1.2) to estimate total abundance, production or biomass at each site. Any parameter that is "per unit area" can be expanded by the compensation ratio to take into account the difference in habitat area, and this ideally should be done at each trophic level.

5.2.1.2 Individual-Based Biotic Variables: Individual performance is often overlooked in monitoring and assessment work as population scale variables are of more concern to managers. Differences in body size, physical condition, growth rate, parasite load and behaviour can yield important insights to the mechanisms involved. For example, poor growth may indicate food limitation or marginal water quality conditions. A major advantage of these measures is their high statistical power relative to most population based measures (Osenberg et al. 1994). We recommend measuring individual growth rate and condition of target species because of this sensitivity to change. Once again, less mobile and easily measured taxa such as invertebrates should also be included as they are likely to provide the most sensitive measures. Methods will usually require individually marked animals and can be incorporated into estimations of abundance using mark-recapture techniques.

5.2.1.3 Community Structure and Diversity: Community structure, the composition and relative abundance of species at a site, is usually very sensitive to ecological change. Differences in community structure can be readily quantified using similarity indices and measures of diversity (see Krebs 1989), but interpreting these ecologically can be very difficult (Karr 1998). In response, biologists have developed and calibrated multi–metric indices (e.g. indices of biotic integrity) that use community structure information to compare sites against regional baseline conditions for specific habitat types (Karr 1998). They do this by combining a suite of community structure measures into a single index number. The index places a site of a given type along a continuum ranging from 'pristine' to 'severely degraded'. Fish based indices of biotic integrity (IBIs) have been widely applied (e.g. Steedman 1988, Roth et al. 1996, Langdon 2001, Lyons et al. 2001, McCormick et al. 2001), but are ill-suited to some areas of Canada (mainly British Columbia and the Territories) where species diversity is naturally low (Karr 1998). Here IBIs based on macroinvertebrates (Kleindl 1995, Karr 1998), or periphyton (Hill et al. 2000) will likely prove more useful (but see Mebane et al. 2003). We recommend regionally calibrated fish or macroinvertebrate based IBIs in site effectiveness monitoring and encourage development of other multi-metric indices of ecosystem function using the guidelines given by Jackson et al. (2000). As discussed in section 4.2.1.2, the Canadian Aquatic Biomonitoring Network (CABIN) is a good example of a common bioassessment approach with standardized protocols. It uses the reference condition approach (Reynoldson et al. 1997) to determine whether differences in organisms between reference sites and test sites indicate any impairment at the test site.

5.2.1.4 Water quantity: The pattern of a site's water levels and currents over time, its hydrograph, is one of the fundamental determinants of its habitat. In streams fluvial processes physically shape habitat through interactions with local geology and vegetation (Poff and Ward 1990, Poff and Allan 1995) and changes in discharge can dramatically alter the types and amount of habitat available (Stanley et al. 1997). In wetlands and intertidal zones the frequency and duration of inundation controls the community structure of plants and low mobility animals (Richter et al. 1996). Salinity in estuaries is a result of the balance between river discharge and tidal conditions. This universal importance of water quantity to fish habitat dictates that monitoring some aspect of it is usually required. Continuous data collection using some form of logger provides the best information.

In freshwater, methods are well established (Dunne and Leopold 1978). The Water Survey of Canada (http://www.smc-msc.ec.gc.ca/wsc/index) maintains 2,481 monitoring stations on inland streams, rivers and lakes. In marine and estuarine settings the most important variables are likely to be wave energy, current direction and strength, depth and extent of inundation, and changes in these over the tidal cycle (Levings and Nishimura 1996). DFO maintains and distributes tide and water level data through its Marine Environmental Data Service (MEDS; http://www.meds-sdmm.dfo-mpo.gc.ca/meds/Home_e.htm).

5.2.2 How to measure it

Rather than reiterate methodological details that are well described elsewhere we present a list of useful references organized by variable and habitat type (Table 3).

Table 3: References for sampling methods in site effectiveness monitoring.

Topic	Reference	Notes
Comprehensive	(Barbour et al. 1999)	Streams and rivers
	(Hauer and Lamberti 1996)	Streams
	(MacDonald et al. 1991)	Streams
	(Robinson et al. 1996)	Marine
	(Krebs 1989)	Abundance/density/diversity estimation
Physical Habitat Surveys	(Bain and Stevenson 1999)	Book; Freshwater habitats
	(Kondolf and Micheli 1995)	Streams
	(Moore et al. 1997)	Streams
	(Williams 1993)	Marine/Estuarine
	(Booth et al. 1996)	Marine
	(Robinson et al. 1996)	Marine
	(Larkin and Slaney 1996)	Sedimentation
	(Van Horn and Horn 1996)	Quantitative photo-monitoring
Fish Sampling	(Murphy and Willis 1996)	All aspects of fish sampling
	(Angermeier and Smoger 1995)	Species diversity and relative abundance
	(Cao et al. 2001)	Species presence/absence/diversity
	(Patton et al. 2000)	Species presence/absence/diversity
	(Hankin and Reeves 1988)	Abundance; snorkel surveys
	(He and Lodge 1990)	Abundance; minnow trapping
	(Reeves et al. 1991)	Abundance by life stage
	(Goede and Barton 1990)	Individual based measurements
	(Karr 1998)	Index of biotic integrity
	(Steedman 1988)	Index of biotic integrity; Ontario

Macroinvertebrate Sampling	(Barbour et al. 1999)	General methods
	(Karr 1998)	Benthic index of biotic integrity
	(Kleindl 1995)	Benthic index of biotic integrity
	(Environment Canada 2004)	CABIN field sampling methods
Periphyton Sampling	(Barbour et al. 1999)	General methods
	(Hill et al. 2000)	Periphyton index of biotic integrity
Riparian Vegetation	(Kondolf and Micheli 1995)	Transects
	(Oikos Ecological Services Ltd. and T. Johnson and Associates 1996)	General Methods
	(Mills and Stevenson 1999)	General Methods
Water Quantity	(Dunne and Leopold 1978)	Streams
	(Richter et al. 1996)	Streams
Water Quality	(Environment Canada and Fisheries and Oceans Canada 1993)	General methods
	(American Public Health Association (APHA) 1995)	General methods

5.3 OBJECTIVE 3: To document how the project affected social values in the community

The opinion survey methods described for routine monitoring (section 4.3) will generally suffice for site effectiveness monitoring. Analysis of the data should be more rigorous and use contingency tables that compare the observed frequency of categorical responses to those expected at random (see section 5.5.2.4).

5.4 EXPERIMENTAL DESIGN

Quantitative experimental designs are used to establish with some known degree of certainty that an observed change is due to a project's impact rather than to mere chance or some other unknown effect. In the following sections we outline some basic features of good experimental design, and identify preferred designs for site effectiveness monitoring of habitat compensation, stewardship, and habitat creation projects.

5.4.1 Baseline Data and Control Sites

We begin our discussion by considering a highly simplistic example aimed at illustrating some basic principles of experimental design. Imagine that we have just completed a habitat restoration project. We might like to know:

a) Has juvenile density of a particular species increased at the site?
b) If it has, is the increase due to recruitment within the site, or did the fish simply move in from adjacent habitats?
c) If recruitment has increased, is it due to the restoration or is this just a particularly good year for fish?

To answer question a) we need estimates of juvenile density at the site both before and after the project was built. The difference between the two is our estimate of the change in site density. The 'before' estimates constitute the study's baseline values against which change is detected.

Question b) can be answered if we have density estimates both before and after the project was built for habitats adjacent to the site. If density declines around the site while going up within it after the project is built, it suggests that fish are simply immigrating into the new habitat. If density in the adjacent habitats does not decline, but increases at the project site it suggests that recruitment has increased there. The adjacent habitats are acting as local control sites in the experimental design.

Answering question c) also requires control sites, but these should be far enough away from the restoration site to avoid being influenced by it. The minimum distance will vary between target species depending on their movement patterns. If juvenile density at these distant control sites is higher after the project is built than it was before, we have evidence that at least part of the increased density we saw at the restoration site is due to it simply being a good year for fish.

In summary, to convincingly demonstrate that our restoration project has caused a real increase in juvenile fish production our data must show three things:

- that density increased from baseline values at the restoration site after work was completed
- that density in local control sites did not decline enough to account for the change
- that density in distant control sites did not increase enough to account for the change

The study we have described uses a type of Before, After, Control, Impact (BACI) experimental design. It requires that variables be measured "before" and "after" the treatment (project) at both "control" and "impact" (project) sites. It is also the simplest possible spatially-nested design, with controls at two scales ("local" and "distant"). We will be discussing variations and applications of both of these design concepts in more detail later (sections 5.4.7 to 5.4.9).

5.4.2 Replication and Pseudoreplication

Replicate samples are independent measurements of a variable. If too few are used or if natural variance is very high, estimates of means, medians, and variance will be very uncertain, making it difficult detect change. Target species density, habitat features and water chemistry may also vary widely among habitats within a medium or large-scale project. In these cases sampling should either cover the entire site or be stratified by habitat type. In stratified designs, one or more sections of each habitat type within a site are sampled intensively and the results are extrapolated to unsampled areas of the same type (Krebs 1989).

Using replications from one scale to erroneously support conclusions on a larger scale is termed pseudoreplication (Hurlbert 1984). For example, perhaps we wish to measure the density of eelgrass in restored beds several years after they were planted. There are several such restoration sites in the region. We begin at one site, which contains six transplanted beds, by counting stems on 10 replicate quadrats scattered randomly through one bed which is conveniently located beside the road (bed 1; Figure 2). Our data should give us a fairly precise estimate of the average stem density in this bed, but we cannot legitimately generalize our results to the site scale because the average stem density in bed 1 may be much higher or much lower than the average in the other five beds, perhaps due to differences in shading or wave action. If we had used 10 quadrats in *each* of four randomly selected beds, we would have 40 samples, but only *four replicates* of restoration impacts on eelgrass at the site scale. Finally, if we are really trying to estimate the average stem density of eelgrass in restoration sites at the regional scale, we still have only one replicate (the average for the whole site). We would have to repeat all of the measurements at several different restoration sites to obtain a meaningful estimate of the regional average.

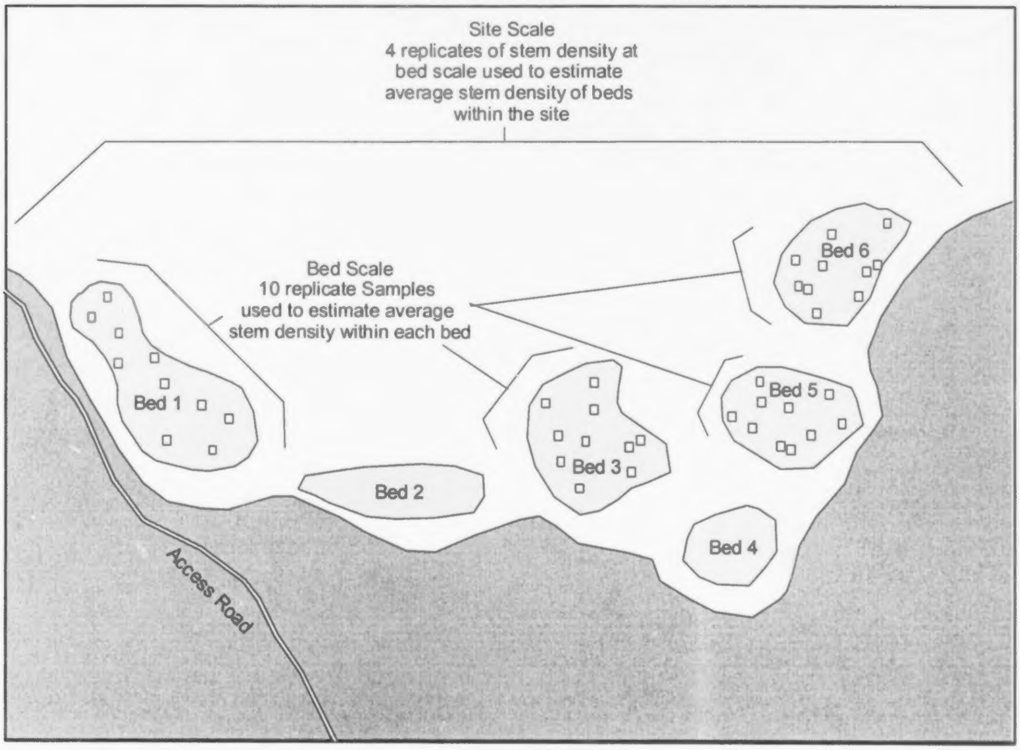
Site Scale
4 replicates of stem density at
bed scale used to estimate
average stem density of beds
within the site
Bed Scale
10 replicate Samples
used to estimate average
stem density within each bed
Bed 1
Bed 2
Bed 3
Bed 4
Bed 5
Bed 6
Access Road

Figure 2: Replication, pseudoreplication and scale in a study of stem density in eelgrass beds. At the bed scale 10 replicate quadrats (white squares) are used to estimate average stem density within a specific bed. At the site scale there are only four replicate measurements of stem density within beds. To treat sample size at the site scale as 40 or at the regional scale as four, would be a pseudoreplication error.

5.4.3 How Many Replicates Are Necessary?

Increasing the number of replicate samples increases the precision of estimates of a variable's characteristics (mean, median, variance, etc.). The number required to achieve a desired level of precision depends on the variance among measurements. If we want to estimate a mean within 10% of its true value, for example, we will need many more samples for a high variance variable (e.g. number of fish per trap) than for a low variance one (e.g. dissolved oxygen concentration in a riffle). Table 4 offers some sample size guidelines for some

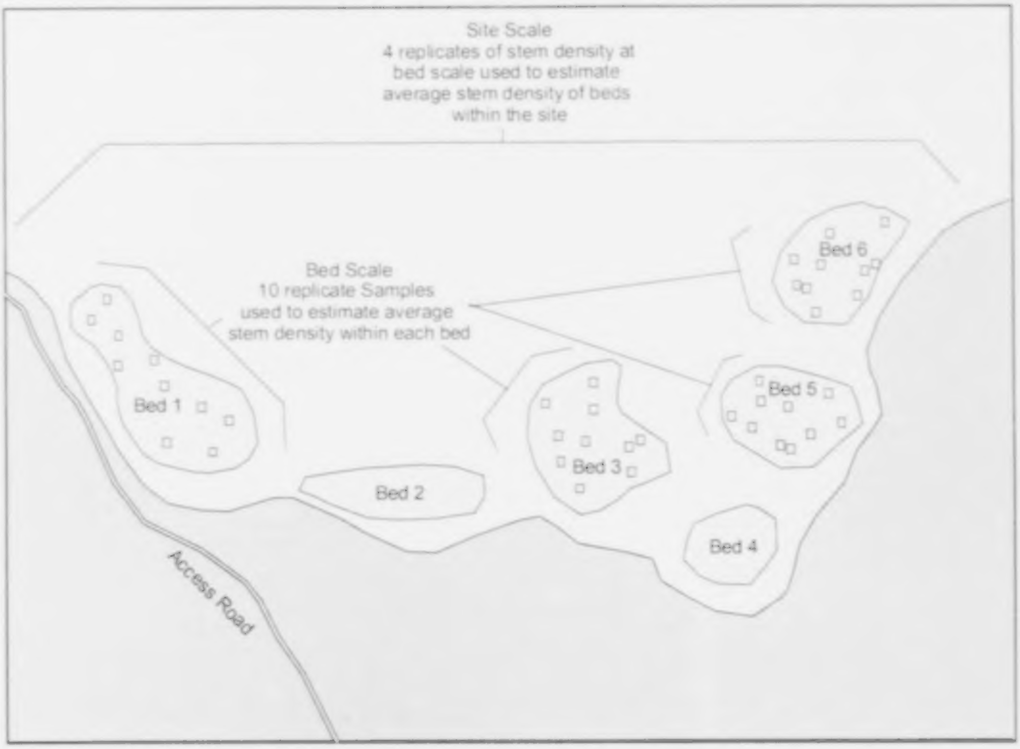
Site Scale
4 replicates of stem density at
bed scale used to estimate
average stem density of beds
within the site
Bed Scale
10 replicate Samples
used to estimate average
stem density within each bed
Bed 1
Bed 2
Bed 3
Bed 4
Bed 5
Bed 6
Access Road

Figure 2: Replication, pseudoreplication and scale in a study of stem density in eelgrass beds. At the bed scale 10 replicate quadrats (white squares) are used to estimate average stem density within a specific bed. At the site scale there are only four replicate measurements of stem density within beds. To treat sample size at the site scale as 40 or at the regional scale as four, would be a pseudoreplication error.

5.4.3 How Many Replicates Are Necessary?

Increasing the number of replicate samples increases the precision of estimates of a variable's characteristics (mean, median, variance, etc.). The number required to achieve a desired level of precision depends on the variance among measurements. If we want to estimate a mean within 10% of its true value, for example, we will need many more samples for a high variance variable (e.g. number of fish per trap) than for a low variance one (e.g. dissolved oxygen concentration in a riffle). Table 4 offers some sample size guidelines for some commonly measured variables. We offer them with the caveat that the actual number required in a specific project setting will commonly differ depending on the observed variation among replicates, the level of precision required and project area. We recommend using *a priori* power analysis (Mapstone 1995) to check and modify these guidelines before they are applied to any specific situation.

Table 4: Minimum number of replicates recommended for sampling methods commonly used in site effectiveness monitoring.

Variable	**Sampling Method**	**Minimum Number of Replicates**
Fish Abundance/Density and Biomass	Traps	Ten sets per habitat type; proportionally more as project area increases
	Backpack Electroshocker (3 pass removals)	Two stop-netted sections per habitat type; proportionally more as project area increases
	Seine	Three hauls; proportionally more as project area increases; area per haul depends on habitat
	Gill Nets (non-lethal sets e.g. 15 minutes)	Three sets per mesh size; proportionally more as project area increases
Fish Presence/ Diversity	Any	Until species accumulation rate asymptotes in relation to effort; in streams, sample length equal to minimum of 10 stream widths (more usually required); (Angermeier and Smoger 1995, Cao et al. 2001)
Fish Growth/Condition	Any	10-30 individuals per species and/or life stage
Macroinvertebrates	Surber or Hess Sampler	Four replicates per sampling location One location adequate for small sites
Periphyton	coverage	Three points on each of three transects per habitat type sampled
	biomass/diversity	Four samples per habitat sampled; combined area at least 0.3 m^2
Water Quality Samples	Meter Reading or Grab Samples	Duplicate samples/readings per sampling location
Riparian Density	Band Transects	Three transects, increase with area to maximum of 20 for very large sites

5.4.4 Statistical Power

The need for *a priori* power analysis arises because of a tradeoff. When testing for statistical significance, two types of errors can occur. We can find an effect where none really exists (Type 1 error, probability = α) or we can fail to detect a real effect (Type 2 error, probability = β). Unfortunately when we reduce the risk of committing one of these errors, we automatically increase the risk of committing the other (Zar 1999).

Monitoring studies, following a long tradition in ecological research, virtually always focus on minimizing the probability of committing a type I error (finding an effect where none exists), arbitrarily setting its risk at 5% (α=0.05). This is generally appropriate for research, but will often mislead management decisions by greatly increasing the risk of failing to detect real effects (Peterman 1990, Mapstone 1995). For example, Mapstone (1995) reports that many environmental impact assessments conclude that a development had no effect when an 80-100% change in the measured variable would have been required to find one. He also proposes a solution to the problem that explicitly weighs the risks of type 1 and 2 errors at the design stage (see case study 3 in section 7.3 for example). The critical steps are:

1. Establish the effect size that must be detectable (e.g. 25% change in biomass).
2. Establish a ratio (k) of α to β based on the perceived risk of committing type 1 and type 2 errors (e.g. 1).
3. Set α=kβ (α=β if k=1) and, starting with α =0.05, apply power analysis (Peterman 1990, Mapstone 1995) to determine the sample size necessary to achieve α=kβ
4. Adjust α and recalculate power. Repeat iterations, trading off monitoring costs (sample size, frequency and duration) against risks of type 1 and type 2 errors.

5.4.5 Selecting Control Sites

We recommend that three control sites be used in most cases (one local and two distant). This allows spatial nesting to permit examination of fish movement effects on local abundance (see section 5.4.1) and provides insurance in case of problems with one control site (Stewart-Oaten and Bence 2001).

Control sites should:

- Be of similar character to pre-impact project sites. Although in BACIP studies (section 5.4.7), they are not assumed to be identical to pre-impact project sites, minimizing differences is likely to increase a study's power to detect change.
- Be an appropriate distance from the project site in relation to distances typically moved by the species studied (e.g. twice maximum annual displacement observed).

- Be free from confounding influences (e.g. a different HADD) that could produce trends in control site variables. BACIP analysis could falsely attribute resulting changes in control-project site differences to the project being monitored (Figure 3).

Brinson and Rheinhardt (1996) advocate using regional reference sites as (in effect) common control sites for projects in a given habitat type. This facilitates direct comparison between projects of the same type. The major difficulty with the approach is the expense and logistic difficulties in completing comprehensive assessments covering a range of parameters at different trophic levels for a suite of regional reference sites as well as encompassing the full range of naturally occurring habitat types. We recommend that regional reference sites be established on a trial basis for one or two of the most common habitat types involved in compensation projects. An example of this approach at one trophic level is CABIN, a network of reference sites of benthic invertebrate communities that has been developed by Environment Canada (see section 4.2.1.2).

5.4.6 Frequency and Duration of Monitoring

Monitored variables will rarely move in a smooth trajectory from one level to another in response to a habitat project (Frissell and Ralph 1998, Zedler and Callaway 1999). Usually there will be some complex, transient response such as a sharp increase followed by slow decline, or cycles of decreasing amplitude (Walters and Holling 1990). Detecting these patterns against the background noise of natural variation depends upon sampling frequently enough for long enough.

Monitoring frequency should be constant and low enough to minimize temporal autocorrelation (section 5.4.8.2, Stewart-Oaten and Bence 2001). It should be the same in before and after periods to ensure that cyclic patterns (e.g. seasonal changes) are represented in both data sets in the same manner (Smith et al. 1993).

In the past, pre-project monitoring duration has typically been limited to a single year. This practice prevents the separation of project impacts from natural year-to -year variation, a problem that will plague both proponents and approval agencies as unmeasured annual variation can either mask or exaggerate project effects (see case study 3 in section 7.3). Bryant (1995) recommended four to six years of baseline monitoring for watershed and stream restoration projects. Other authors recommend extending it over at least two life cycles of monitored species to ensure that some intergenerational variation is captured (Everest et al. 1991). We recommend at least two years of pre-project monitoring if feasible to provide at least some measure of inter-annual variance. We also suggest a minimum of three sampling periods per year for biotic variables to provide some replication for estimation of their pre-project levels.

Post-project monitoring should extend for 10 years or two life cycles of target species, but need not be continuous (Hunt 1976, Bryant 1995). We recommend three, pulsed, two-year periods of effectiveness monitoring (immediate = years 1 and 2, short term = years 5 and 6, medium term = years 9 and 10). This allows statistical testing for NNL in each of the three periods separately, which provides valuable information on recovery rates and avoids averaging impacts over a ten-year period – a practice that is likely to mask real recovery in later years.

5.4.7 BACIP Designs

In section 5.4.1 we introduced the BACI design and the concept of nested control sites. Various combinations of these constitute the best available family of experimental designs for assessing human impacts on natural systems (Underwood 1991, Frissell and Ralph 1998, Stewart-Oaten and Bence 2001). BACI designs allow observed trends in a project site to be legitimately attributed to on or off-site influences. Refining BACI though the addition of spatially nested control sites over a hierarchy of scales (watershed, segment, reach, etc.) permits the identification of off-site factors that influence the site over different scales (Minns et al. 1996, Frissell and Ralph 1998). They can be applied to any numeric variable subject to several assumptions (section 5.4.8).

There are two main methods of analyzing BACI studies (see Stewart-Oaten and Bence 2001 for a comprehensive review). Paired BACI models (BACIPs) focus on differences in mean values between control and project sites before and after project implementation. In effect the 'control' sites are used as covariates to reduce the effects of large-scale temporal variation that affects both control and project sites (Stewart-Oaten and Bence 2001). A major advantage of the design is that mean values of variables at control sites are not assumed to be equal to those at the project site before construction. Instead the *difference* between them is assumed to be constant (Figure 3).

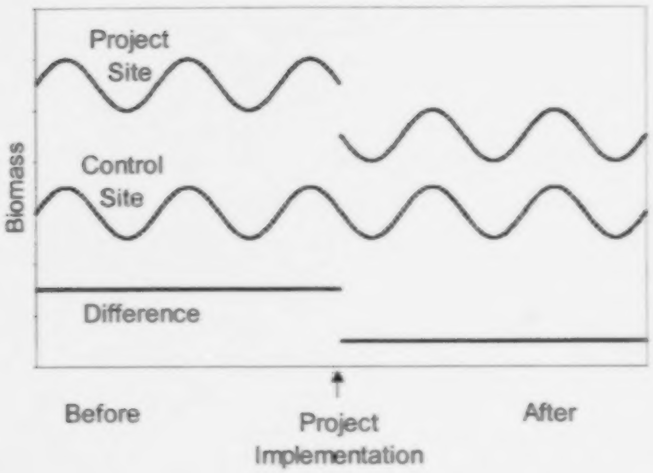

Figure 3: Hypothetical data from a BACIP experimental design applied to biomass. Mean biomass cycles seasonally and is lower at the control site than at the project site. The difference between control and project sites remains constant within the before and after periods, but decreases in response to project implementation, indicating a negative project impact (adapted from Stewart-Oaten et al. 1986).

Analysis of variance (ANOVA) based models differ in using replicated control sites to estimate variation among 'natural' sites. The ANOVA tests for time (before versus after project implementation) by treatment (control versus project site) interactions (Underwood 1991, 1993). These methods have been criticized on theoretical grounds (Stewart-Oaten and Bence 2001) and fared poorly in a recent comparative test with BACIP (Hewitt et al. 2001). We do not recommend them except when pre-impact data is unavailable and there is no alternative (section 5.4.9.4).

5.4.8 Assumptions of BACIP Designs

The validity of BACIP designs rest on three main assumptions. All should be tested statistically or shown to be plausible by independent arguments based on biological knowledge. A comprehensive discussion on testing these assumptions is beyond the scope of this paper (see Stewart-Oaten et al. 1992), but an overview of some appropriate statistical tests and possible analytical strategies when they are violated is provided in appendix 1. The assumptions are:

5.4.8.1 Additivity: The expected difference in a variable's value between control and project sites must be constant within a period (pre or post-project). This assumption is commonly violated. Examples include situations where abundance is always some fraction (e.g. one half) of control site abundance regardless of absolute numbers, or where a non-project related trend in the variable exists at one of the sites (Figure 4). Depending on the type of violation the effect may be to mask real project impacts preventing their detection or to find project effects where none really exist (e.g. Murtaugh 2002). Careful selection of control sites (section 5.4.5) can minimize the risk of violating the additivity assumption, and mathematical transformation of variables prior to analysis can often correct for violations.

5.4.8.2 Independence: Observed values from different sampling dates must be independent (i.e. values at one time cannot influence values at the next time). Meeting this assumption depends mainly on ensuring sampling sessions are sufficiently separated in time.

5.4.8.3 Identical normal distributions and homogeneous variances: Deviations from the expected mean difference between control and project sites must be normally distributed with a constant variance among sampling times and between sampling periods (before and after). This assumption is also likely to fail in some way but usually easily corrected for with modifications to the t-statistic, mathematical transformation of variables, and interpretation (Stewart-Oaten et al. 1992, appendix 1).

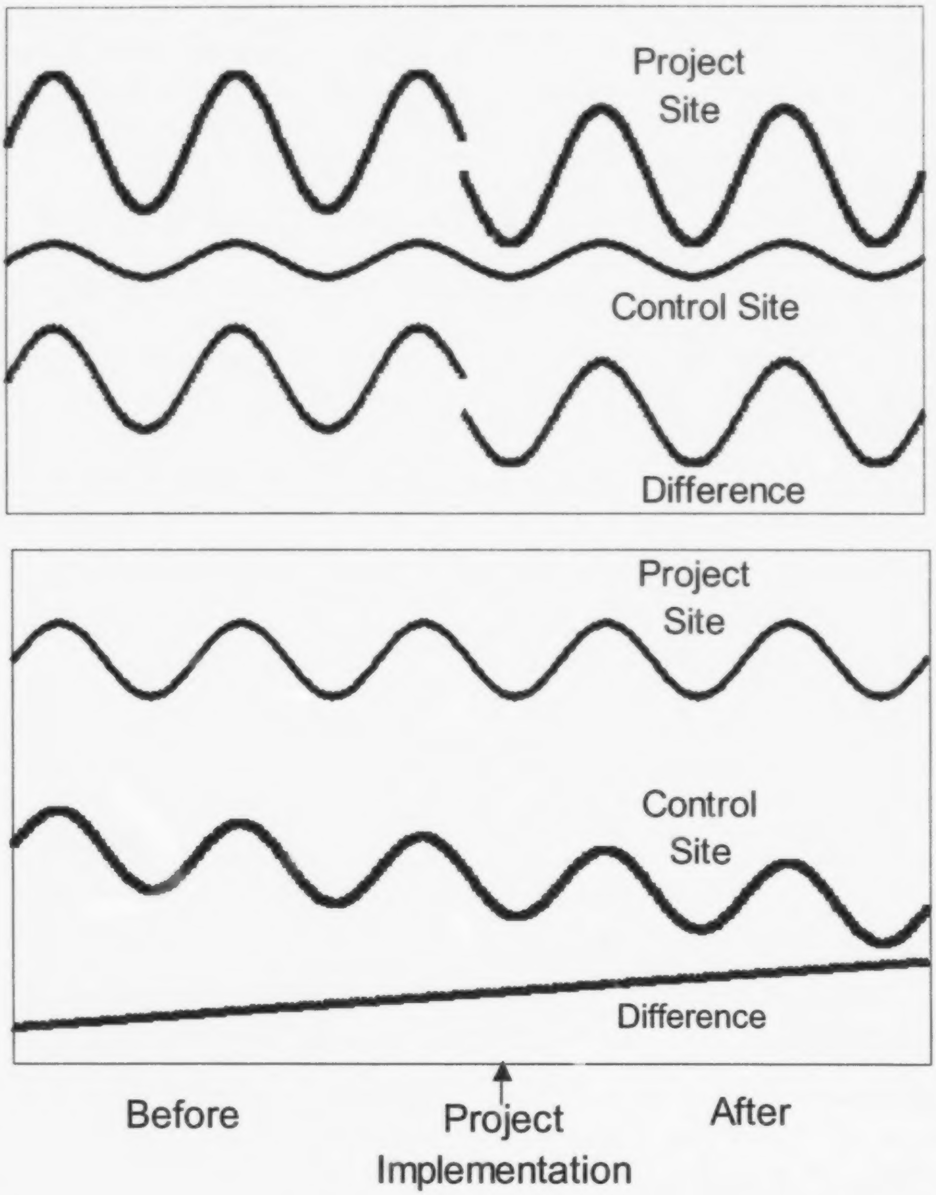
Project
Site
Control Site
Difference
Project
Site
Control
Site
Difference
Before
Project
Implementation
After

Figure 4: Two examples of additivity failure in a BACIP experimental design. In the top panel the biomass at the control site is a constant fraction of that at the project site. The difference between them varies widely and will partially mask the real project effect unless they are log transformed. In the lower panel, there is no project impact, but values at the control site are declining as they cycle. The difference between them increases over time and a project effect is likely to be detected even though it did not occur (adapted from Stewart-Oaten et al. 1992).

5.4.9 Applying BACIP

BACIP designs can be applied to any variable for which we can estimate values before and after project implementation. A typical list would include density, biomass, growth rates and condition of a number of species and/or trophic levels, measures of habitat attributes (e.g. dissolved oxygen, % plant cover) and regionally calibrated indices of biotic integrity.

5.4.9.1 Restoration Projects: BACIP can be applied to habitat restoration projects in its simplest form. The impact of the project (I) on a variable is estimated as

$$(5.1) \qquad I = D_B - D_A$$

where D_B and D_A are the differences between mean values at the restoration and control sites before (*B*) and after (*A*) project implementation (Stewart-Oaten et al. 1986). When we wish to separate effects operating on different scales using local and distant control sites (section 4.6), equation 5.1 is modified to

$$(5.2) \qquad I = (D_{B,Cl} - D_{A,Cl}) - (D_{B,Cd} - D_{A,Cd}),$$

where *Cd* represents the distant control site(s) and *Cl* represents the local control site. Of course the precision of impact estimates must also be calculated (section 5.5.2.3) and reported.

5.4.9.2 Like Compensation Projects: Assessing NNL requires some additional steps. It is important to verify the total area compensated as well as the modified (HADD) area. These area measurements will determine the actual compensation ratio. To assess the impact of a project on a variable, equation 5.1 is applied to the HADD site and the appropriate equation (5.1 or 5.2) is applied to the compensation site. Net change (NC) is then calculated as

$$(5.3) \qquad NC = (CR \bullet I_{Comp}) - I_{HADD}$$

where I_{HADD} and I_{Comp} are the changes in variable at the HADD and compensation sites and *CR* is the actual ratio of compensation habitat area to HADD habitat area. When $NC \geq 0$, NNL of the variable has occurred. These factors, the overall area of change and the magnitude of change per unit area, determine the habitat quantity and the habitat quality. The net change in a variable, and thus the NNL determination, is a function of both these changes in habitat area and habitat productivity and thus should integrate both elements where possible (i.e. where the parameter is "per unit area"). Parameters not expressed in area-specific terms cannot be expanded by the compensation ratio, but are important to detail the range of potential habitat changes and are used as weight of evidence to support NNL determinations.

5.4.9.3 Unlike Compensation Projects: When like compensation is not feasible, proponents may be asked to create or enhance a different type of habitat containing different life history stages and/or species than the one affected by the HADD. On the west coast of British Columbia for example, off-channel pond habitat used by juvenile coho salmon and cutthroat trout populations is sometimes constructed as compensation for loss of mainstem spawning riffles used by adults, eggs, and alevins of steelhead and chum salmon (Swales and Levings 1989). If juvenile habitat is limiting coho and cutthroat populations, net gains in production for these species are likely. If spawning habitat is limiting the steelhead population, which do not benefit from the new ponds, net loss of its habitat will occur regardless of how well the compensation is implemented. The avoidance of these tradeoffs is the primary reason that like compensation is preferred (DFO 1986, 1998, 2002).

When production of different species must be traded off, decisions should compare the impact of both the HADD and compensation on production of the same, later life history stage of both species. Ideally this will be the adult stage in which growth and survivorship is integrated across all life stages and habitats (Lewis et al. 1996). In anadromous species, however, smolt production is preferred as it avoids the confounding influences of fishing mortality and variable ocean conditions (Everest et al. 1991, Kerman and Higgins 1997). Decision analysis methods that compare long term values of alternative policies (see MacGregor et al. 2002) are recommended. To be done well, the approach requires good estimates of survivorship between life history stages in different habitats and knowledge of the habitat type limiting production of each species.

BACIP should also be applied to variables common to both habitats (e.g. macroinvertebrate or periphyton biomass). The weakness of this approach is that the variable may not be related to productive capacity in the same way across habitats. For example, macroinvertebrates may be more available to foraging fish in stream riffles than in pools populated at the same density.

5.4.9.4 When there is no 'before' data: BACI designs cannot be applied without pre-project data. In these situations the best option is an After-Control-Impact (ACI) design which compares project site values directly to those of control sites using analysis of variance methods (see IVRS designs in Stewart-Oaten and Bence 2001). In compensation projects that lack before data, control sites are assumed to estimate conditions at the HADD site if the impact had not occurred and to represent target values for variables. This differs from BACIP in which control sites are used to factor out large scale temporal changes common to both sites (Stewart-Oaten and Bence 2001). Project success is judged in terms of the amount of difference (D) in mean values of a variable (X) between control sites (c), compensation project sites (p), and any modified areas at the HADD site (m) that still have habitat value, such that

$$(5.4)\ Dx = \overline{X}c - \overline{X}p - \overline{X}m\ .$$

As in equation 5.3, compensation site variables, where appropriate, should be expanded by the compensation ratio. For compensation projects, NNL is achieved when $Dx \le 0$ and precision is calculated in the form of confidence limits (section 5.5.2.3).

In non-compensatory habitat creation projects, control sites act as reference sites which the creation project is designed to emulate (Aronson et al. 1995, Kershner 1997). This may be a real site, although many restoration ecologists prefer to use a 'composite description' based on multiple reference sites and supplemental historical and ecological data on the project site (SER 2002).

5.5 DATA ANALYSIS

5.5.1 Exploratory Analyses

Data is often easiest to comprehend when presented visually. Graphs also provide insights into patterns that might warrant testing for quantitative significance and can flag violations of assumptions of those tests (e.g. non-normality, unequal variances, trends within the before period of a BACIP, etc.). At a minimum, we recommend plotting frequency distributions, correlations among variables, and mean (+Standard Error) values over time for all measured variables.

5.5.2 Hypothesis Testing

5.5.2.1 Statistical vs. Biological Significance: In order to interpret a finding that a significant difference does or does not exist we must know what size of difference the test is capable of detecting, and the minimum difference that is biologically important. No two habitats are identical, nor is the same habitat ever identical at two points in time. It follows that with sufficiently sensitive methods and enough replication, statistically significant differences will be found between any two sites and between any two times at a given site. Conversely, if methods are insensitive and/or sample size is inadequate even very large differences may not be detected. In other words, statistical significance is meaningful only so far as it reflects biological significance. Too often the two are treated as synonymous (Krebs 1989, Mapstone 1995, Johnson 1999).

5.5.2.2 Testing for Statistically Significant Effects: In BACIP designs statistical significance is tested for using paired t-tests or more commonly Welsh t-tests (standard t-test modified to account for differences in the number of monitoring sessions and variances between the before and after periods). These methods are described in detail in appendix 1. Separate tests can be made on each of the three 'after' periods: the immediate (1-2 year), the short (5-6 year) and medium (9-10 year) terms. A test's ability to detect an effect of a given size is termed its power ($1-\beta$). Although some authors advocate routinely reporting it when no effect is found (Peterman 1990), more recent work suggests that simple examination of confidence intervals (section 5.5.2.3) around the mean is a more reliable way of assessing adequacy of sampling *post hoc* (Gerard et al. 1998, Johnson 1999, Carey and Keough 2002).

5.5.2.3 Confidence Limits: In monitoring and assessment work the questions of real interest are how large an effect actually occurred and how confident are we in our estimate of its size (Stewart-Oaten et al. 1992). Estimating effect size in BACIP and ACI is a simple matter of subtracting mean difference between control and project sites in the before period from those of the after period (equations 5.1-5.4). From the variance among measurements that make up each mean we can calculate its confidence interval, a range of values which is expected to include the true mean a given percentage (1-α) of the time (Krebs 1989). For BACIP designs, the confidence intervals for effect size can be calculated as

$$(5.5) \qquad (D_A - D_B) \pm t_{df} \cdot SE ,$$

where *SE* is the standard error of the mean as calculated in equation A2 of appendix 1. In ACI studies the procedure is applied to the difference at a particular point in time between project and control sites rather than to before and after periods. This involves substituting the numbers of samples in the project site and the control site(s) for the time period for n_B and n_A when calculating *SE*.

5.5.2.4 Contingency Tables: When observations are divided into categories, contingency tables can be used to examine their patterns. One-way tables summarize the number (or percentage) of times an observed variable fell into each of its categories. Two-way tables summarize the number of times an observation fell into each possible combination of categories of two variables. Multi-way tables are also possible (see Zar 1999). Chi-square analysis of contingency tables allows an investigator to test for significant differences between observed frequencies and those that were expected at random or to fit other hypotheses (Zar 1999).

5.5.2.5 Other Non-parametric methods: When assumptions for t-tests are badly violated (e.g. severe skewness due to many zero values in the data) then non-parametric methods may be utilized as they do not assume the underlying distribution. For example, the ranks of measurements rather than their values may be statistically assessed as they are consequently much less sensitive to the effects of extreme values or distributions. Two methods likely to prove useful in the study designs we have outlined are the Wilcoxan paired sample U test, and the Spearman rank correlation coefficient (Zar 1999). They are the non-parametric analogues to the paired t-test and the Pearson correlation coefficient (r^2), respectively. For minor and moderate violations it is generally preferable to adopt a robust parametric estimator such as the Welch t-test (Stewart-Oaten et al. 1992).

5.6 SUMMARY OF SITE EFFECTIVENESS MONITORING

Table 5: Summary of design objectives and methods for site effectiveness monitoring.

	Description	Section
Objective 1	***To verify that the project was implemented as designed and approved***	5.1
As-Built Survey	Direct comparison with approved design of project configuration, materials, structural integrity, and area (by habitat type), using rigorous topographic survey methods and photography	5.1.1-5.1.2
Post-project Surveys	Same methods used as in as-built survey. Recommended for years 2, 5 and 10 in post-construction monitoring period	5.1.2
Objective 2	***To quantify the net change in habitat productive capacity***	5.2
Approach	Multi-metric approach to assessing habitat productive capacity that includes a broad range of surrogate variables including measures of physical habitat, biological production (e.g. biomass) at a range of trophic levels, and individual measures of fitness (e.g. fish growth and condition)	4.2, 5.2
Experimental Design	BACIP (before-after-control-impact-paired) • Surrogate variables for productive capacity measured at project and control sites before and after project implementation	5.4.7-5.4.9 5.2.1-5.2.2
Control Sites	• One local control for variables involving fish (to correct for movement effects) • Two distant controls as insurance in case of difficulties with one	5.4.1, 5.4.5
Monitoring Duration	• Two years of pre-project monitoring (minimum one year) • 10 years of post-project monitoring	5.4.6
Monitoring Frequency	• Pulsed in three periods of two years each (1 and 2, 5 and 6, 9 and 10) • Sampled three times per monitoring year for most variables (once per year for riparian vegetation)	5.4.6
Typical Variables	• Physical - water temperature - water quantity (area, hydrograph) - water quality (dissolved oxygen, BOD, nutrients, contaminants) • Biological - primary production (e.g. periphyton density and diversity, eelgrass density) - secondary production (e.g. macroinvertebrate density and diversity) - tertiary production (e.g. fish abundance, density and production by species and life stage, fish growth and condition)	5.2.1-5.2.2
Data Analyses	• Three Welsh T-tests per variable. Tests compare differences between control and project sites before construction with differences in the immediate (1-2 yr), short (5-6 yr) and medium (9-10 yr) terms.	5.5.2
Objective 3	***To document how the project affected social values in the community***	5.3
Study Design	Opinion survey questionnaires	4.3.1-4.3.2
Data Analysis	Non-parametric and contingency table analyses	5.5.2.4 5.5.2.5

6. PROGRAM EFFECTIVENESS EVALUATION

Program effectiveness evaluation can be used to study how effective management practices used in projects are functioning and, for example, help assess if the goals of the Habitat Policy or other management objectives are being achieved at the program level. The results of many project level assessments are combined, statistically assessed and compared, allowing managers to rigorously evaluate techniques and management approaches using active adaptive management study designs (see Figure 1). Program effectiveness evaluation requires that practitioners employ consistent methodologies and experimental designs when collecting data and evaluating project success. This approach can be used to evaluate and improve almost any aspect of any type of program. One of the primary objectives of this document is to promote such consistency so that program effectiveness evaluation and large-scale adaptive management can occur in habitat compensation and stewardship projects. For DFO, program effectiveness evaluation should be conducted at both a regional and national level to build on successes and learn from past mistakes.

In the long term, this adaptive management approach will result in more efficient use of resources, the adoption of proven cost-effective methods, and improved transparency and enhanced defensibility of environmental policies and management decision making. We present a suggested approach for program effectiveness evaluation of NNL achievement by habitat compensation projects as an example. A similar approach could be implemented for other aspects of DFO's habitat program (e.g. habitat restoration, education and stewardship, or planning initiatives). The following sections outline the process of program effectiveness evaluation.

6.1 STEPS IN PROGRAM EFFECTIVENESS EVALUATION: HABITAT COMPENSATION EXAMPLE

6.1.1 Definition of management objectives

The first step in program effectiveness evaluation is defining the question that requires answering. In this case for example: "Is DFO achieving its management objective of NNL through habitat compensation efforts?"

6.1.2 Design and implementation of program effectiveness evaluation program

Routine and effectiveness monitoring of compensation projects should be conducted in a consistent manner as outlined in this document to facilitate data compatibility across projects. Copies of monitoring reports and authorization files, including pre and post-impact assessments, engineering drawings, photographic records of project development, and correspondence between the proponent and

DFO should all be collected. These monitoring reports should be reviewed, and the relevant data from each file extracted and entered into a database for analysis (see Harper et al 2001 for an example, Harper and Quigley 2005).

The database should house all data from the individual monitoring reports and enable the various questions identified in the objectives to be answered. It would facilitate the analysis of trends and patterns in habitat compensation and would enable the assessment of whether or not compensation projects are collectively achieving NNL. The final goal is to provide recommendations to improve habitat compensation practices (e.g. what characterizes compensation projects that have successfully achieved NNL?).

6.1.3 Reporting

Regular program performance reports produced from the evaluation program would form the basis for modifications to management approaches essential to adaptive management (see section 6.1.5). Annual technical reports could be produced from the results of these queries and would outline DFO's success in achieving NNL or a NG. An overall balance of habitats lost and gained through compensation projects could also be maintained, and included in DFO's annual report to Parliament.

An additional benefit of program evaluation would be an improved ability for shared learning to improve consistency with respect to habitat compensation management decisions. For example, these performance reports (based on the collective results of all of the region's monitoring reports) could assist practitioners in their determinations of the appropriate financial security of compensation habitat to retain, compensation ratios, monitoring periods, etc.

6.1.4 Evaluation

Strategic field audits of a subset of the compensation projects should be completed to verify the data collected within the routine and effectiveness monitoring reports. Audits of the database should occur as well to ensure accuracy of data entry. Data gaps that will prove problematic in answering the question posed should be identified and addressed.

6.1.5 Feedback loop

The performance reports and strategic audits should be used to summarize the trends, patterns and success of habitat compensation. Furthermore, recommendations should be incorporated into the reports to improve habitat compensation as a habitat management tool. These reports form the beginning of a feedback loop to track improvements and changes over time.

Depending on the outcome of the preceding phases a variety of adjustments to either the problem (i.e. implementation of habitat compensation) or the design of the evaluation program could occur. For example, if the evaluation phase indicated poor quality of data being collected, training on assessment techniques to improve quality control on future projects could be provided and/or different methods could be adopted. Changes to policy could occur through guidelines, best management practices, or fact sheets, developed to adjust the implementation of habitat compensation based on the reports generated through the evaluation phase. The entire cycle is then repeated to assess the question based on the modifications made to habitat compensation (or whatever management program, strategy or project technique being evaluated). This feedback phase can also have spin-offs to other sectors of DFO based on the recommendations from the reports generated. For example information/knowledge gaps could direct applied research in Science Branch or land use activities with chronic poor compliance could direct enforcement efforts through the Conservation and Protection Branch.

7. CASE STUDIES

The following four case studies have been developed as examples to illustrate the methods and analyses recommended in earlier chapters over a range of project and habitat types. Although they are based on real projects, names, locations, and many details have been altered. For reasons of brevity and to avoid repetition each highlights particular aspects of the monitoring and assessment process (Table 6). Lists and brief descriptions of all measured variables are given, but we only present analyses of selected variables for each case study.

Table 6: Overview of case studies detailing project type and monitoring approaches and challenges each is designed to illustrate.

Case Study	Type	Highlighted Features
1. Jenson Brook Wetland Restoration	• Routine Monitoring • Habitat restoration project • Wetland and stream habitat • Coastal British Columbia	• Routine monitoring methods • Monitoring sociological impacts
2. Big Trout River Sawmill Expansion	• Site effectiveness monitoring • Like-for-like compensation project • Stream habitat • Interior British Columbia	• Site effectiveness monitoring methods • Experimental design principles for like compensation projects • Use of multiple variables and control sites in no-net-loss assessment • Importance of statistical power in no-net loss assessment
3. Lost Creek Pipeline Crossing	• Site Effectiveness Monitoring • Unlike-for-like compensation project • Stream habitat • Northern Ontario	• Site effectiveness monitoring methods • Experimental design principles for unlike compensation projects • Assessing tradeoffs among species • Importance of a two-year baseline monitoring period
4. Gillis Cove Marina	• Site Effectiveness Monitoring • Like-for-like compensation • Estuarine habitat • Nova Scotia	• Site effectiveness monitoring methods in an estuarine environment • Accounting for residual productivity at a HADD site

The monitoring and analysis presented in each of these case studies is very comprehensive, often involving multiple monitoring events, to demonstrate steps for example purposes. The most important principles outlined in this guidebook (reference and control sites, replication, pre-impact information) are the key elements upon which to focus any monitoring program. Scaled down versions of this type of work are still acceptable if they incorporate these elements.

The intensity of a monitoring plan should be scaled commensurate with how large and/or complex the project is, as well as what degree the project is judged to be a risk to the resource. Risk can be ascertained in a variety of methods, and should include consideration of the magnitude, severity, reversibility and geographical extent of the potential impacts, and the sensitivity and fragility of fish and fish habitat in the receiving environment of the potentially impacted habitat.

7.1 CASE STUDY 1: JENSON BROOK WETLAND RESTORATION

7.1.1 Site and Project History

Jenson Brook is a third order stream flowing through agricultural land in the Cedar River Valley (Figure 5). Although once locally renowned for its strong runs of coho salmon, few fish have returned to spawn in recent years. Following the appearance of an article on the problem in the local newspaper, a small group of fly fishers and naturalists in nearby Cormorant Landing formed the Jenson Brook Streamkeepers. They were united by the desire to restore the health of the stream and, in particular, to rebuild the depleted run of coho. At one of their first meetings the DFO community advisor for the region gave them a copy of a watershed assessment conducted by department biologists a few years earlier.

According to the report, a number of other fish species also inhabited Jenson Brook (Table 7). Of these, the chum salmon population seemed to be doing well, steelhead returns and resident rainbow trout numbers were stable, but anecdotal evidence suggested that the cutthroat trout populations had also been in decline for some time. No information existed on the trends or current status of non-salmonids.

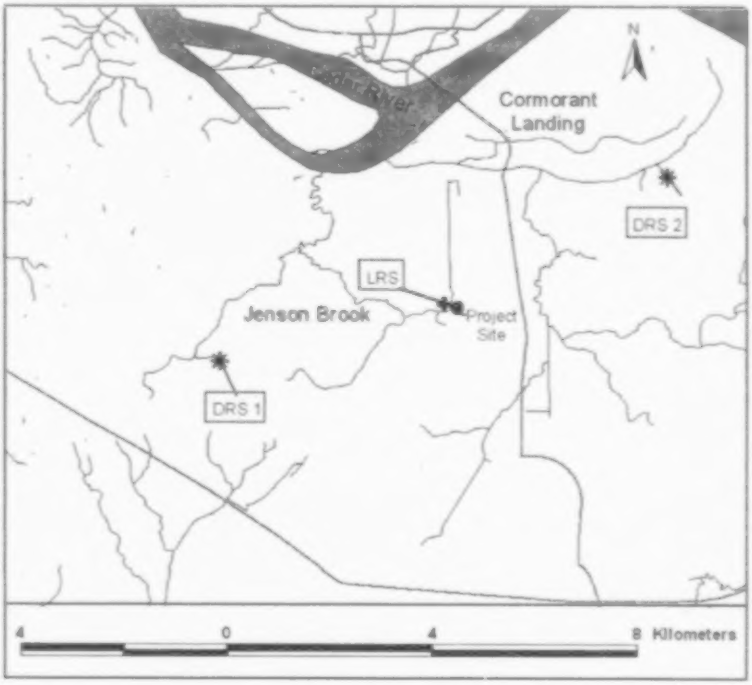

Figure 5: Locations of Jenson Brook project site in relation to its local (LRS) and distant reference sites (DRS 1 and DRS 2).

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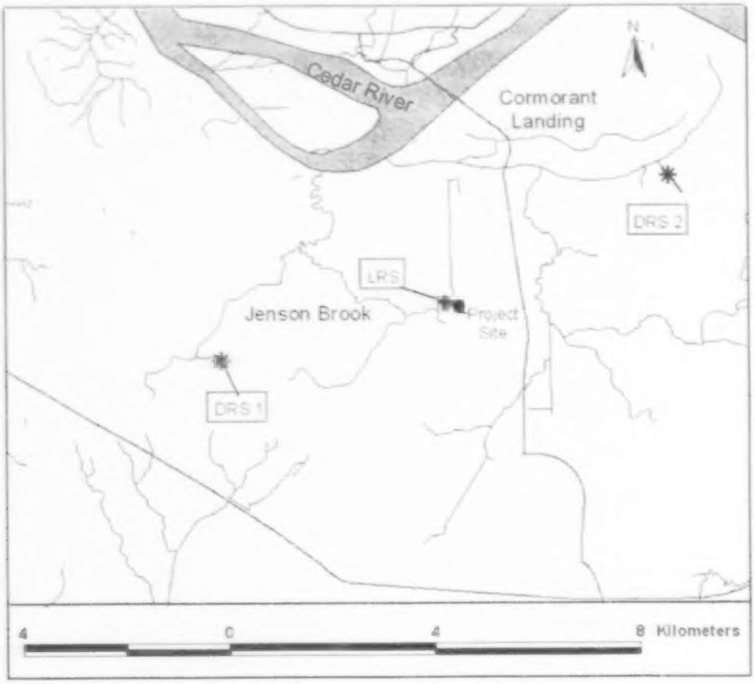

Figure 5: Locations of Jenson Brook project site in relation to its local (LRS) and distant reference sites (DRS 1 and DRS 2).

Table 7: The fish community of Jenson Brook.

Family	Species	Common Name	Life Stage
Salmonidae	*Oncorhynchus kisutch*	Coho salmon	Spawning and rearing
	Oncorhynchus keta	Chum salmon	Spawning only
	Oncorhynchus clarki	Cutthroat trout	All life stages
	Oncorhynchus mykiss	Rainbow trout	All life stages
	Oncorhynchus mykiss	Steelhead	Spawning and rearing
Cyprinidae	*Ptchocheilus oregonensis*	Northern pikeminnow	All life stages
	Richardsonius balteatus	Redside shiner	All life stages
	Rhinichthys cataractae	Longnose dace	All life stages
Catostomidae	*Catostomus macrocheilus*	Large-scale sucker	All life stages
Cottidae	*Cottus asper*	Prickly sculpin	All life stages
Gasterosteidae	*Gasterosteus aculeatus*	Threespine stickleback	All life stages
Petromyzontidae	*Lampetra sp.*	Lampreys	All life stages

The report found that water quality in the creek was still quite good and that the historical spawning riffles were largely intact. The extensive wetlands that had surrounded Jenson Brook prior to European settlement, however, had virtually all been drained to create agricultural land. This had the combined effect of dramatically increasing flows during the winter rainy season and eliminating the off-channel refuges that fish depended on to escape strong currents. The report authors had concluded that both the coho salmon and cutthroat trout populations were limited by a lack of off-channel habitat for juveniles. They believed that a modest amount of restoration in some key locations would address the bottleneck limiting these populations and would probably benefit some of the non-game species as well.

One of the Streamkeepers knew of a low-lying field bordering Jenson Brook that had been left fallow for a number of years. A few rushes and sedges had sprung up in the lower spots and there were even some young willows taking root adjacent to the stream. One of the ditches bordering the field flowed year-round with cold clear water and had been identified in the report as a channelized tributary of Jenson Brook. The group approached the farmer and learned that he had decided not to farm the field, as he thought it would cost more to return it to a productive state than it would likely yield. He was an avid fly fisher and liked the idea of a habitat restoration project on his property. The group also had long-term ambitions to restore the health of Jenson Brook as a whole and recognized that they could use this initial project to educate and inspire the community to achieve this. With all this in mind, they agreed on three main objectives for the project.

7.1.2 Project Objectives

- To instill and develop public awareness and support for fish and fish habitat issues in the local community.
- To strengthen the conservation ethic in the local agricultural community.
- To increase coho salmon and cutthroat trout densities in the restoration site to those of a productive, natural off-channel wetland.

7.1.3 Project Design

With some assistance from DFO staff and a local consultant, the Streamkeepers developed a proposal to divert the channelized tributary through a series of constructed ponds before it joined the mainstem of Jenson Brook (Figure 6). The pond habitat would be complexed with large quantities of woody debris and the channel joining the ponds would feature several undercut banks. The shallow margins of the ponds would be heavily planted with aquatic plants and the surrounding riparian zone replanted in native trees and shrubs. Although the majority of the habitat consisted of deep-water pools, a few short riffles served to control water levels and to provide a small amount of spawning habitat on the project site.

7.1.4 Monitoring and Assessment Goals

- To document changes in public awareness and attitudes towards fish and fish habitat issues among members of the agricultural and broader community.
- To document changes in populations of coho salmon, cutthroat trout and other fish species produced by the project
- To document other ecological and water quality changes as indicators of the new habitat's productive capacity and to suggest reasons for changes in the fish community, if observed.

7.1.5 Monitoring Program

The Streamkeepers, in consultation with DFO biologists, developed a routine monitoring program that included a variety of biological and physical variables (Table 8). They compared values between their constructed off-channel wetland and two natural off-channel wetlands. One of these distant reference sites (DRS 1) was located on the west fork of Jenson Brook while the other (DRS 2) was situated in a neighbouring watershed (Figure 5). In addition they monitored the fish community in a local reference site (LRS), a 500 m section of the main stem of Jenson Brook adjacent to the restoration (project) site, and monitored spawning activity in both the LRS and in similar main stem sections beside DRS 1 and DRS 2. For an explanation of this approach see section 4.6. In the year prior to project construction, the group collected data on the fish related variables. This provided them with a baseline from which to assess the project's impact on the adjacent mainstem. In the year following construction they conducted an as-built survey and began monitoring all of the variables listed in Table 8. This was repeated in the second, fifth and tenth year following project construction.

It is important to note that this approach is essentially a synthesis of five monitoring events (years -1, 1, 2, 5, and 10), and in most instances is more comprehensive than what would be involved any single "routine" monitoring event. The examples provided are designed to illustrate the principles involved and the benefits of a comprehensive monitoring program.

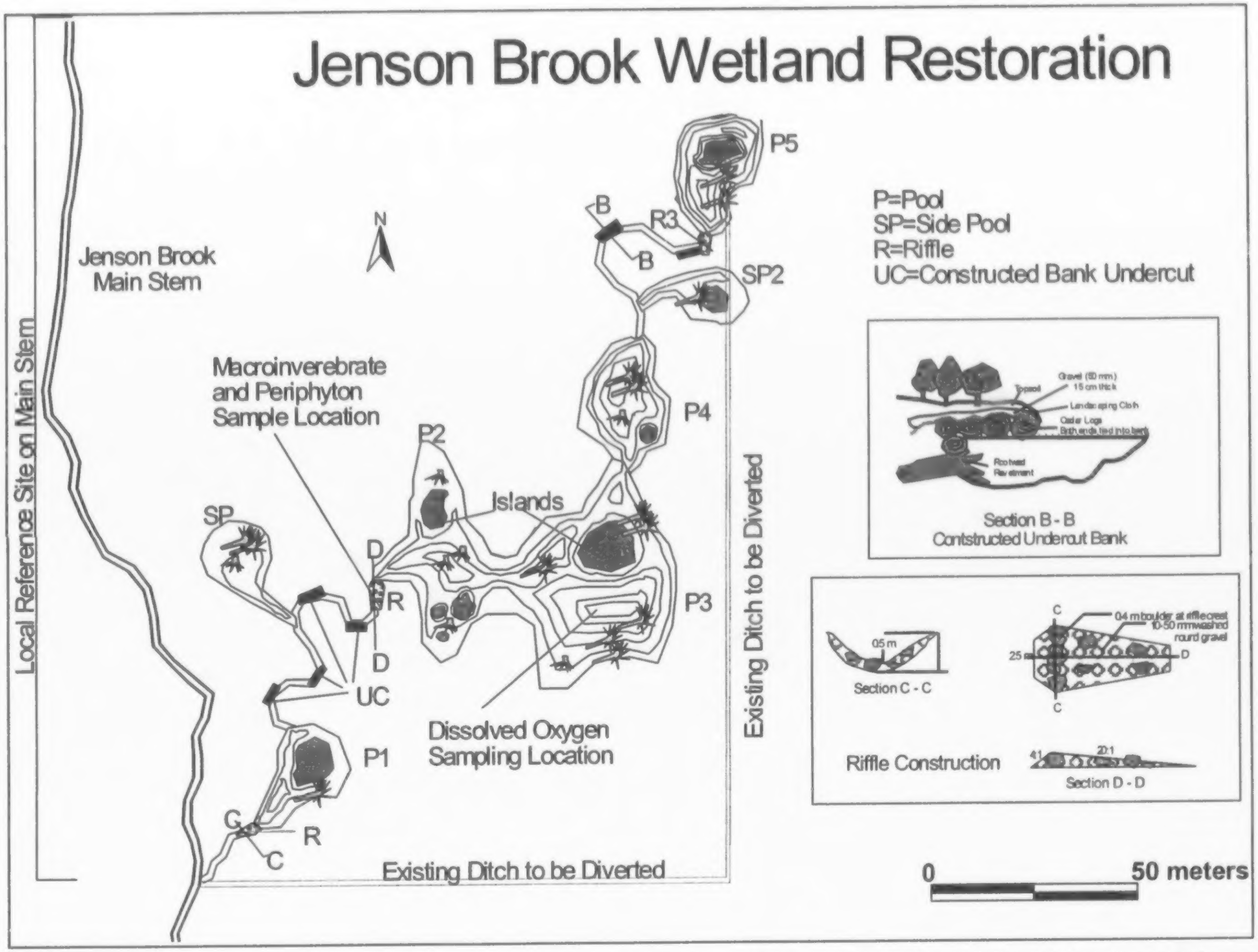
Jenson Brook Wetland Restoration
Local Reference Site on Main Stem
Jenson Brook Main Stem
N
Macroinverebrate and Periphyton Sample Location
SP
P2
Islands
D
R
D
UC
P1
G
C
R
Dissolved Oxygen Sampling Location
Existing Ditch to be Diverted
P3
P4
-B
B
R3
SP2
P5
Existing Ditch to be Diverted
P=Pool
SP=Side Pool
R=Riffle
UC=Constructed Bank Undercut
Gravel (50 mm) 15 cm thick
Topsoil
Landscaping Cloth
Cedar Logs Both ends tied into bank
Rootwad Revetment
Section B - B
Contstructed Undercut Bank
0.5 m
Section C - C
C
0.4 m boulder at riffle crest
10-50 mm washed round gravel
25
D
C
Riffle Construction
4:1
20:1
Section D - D
0
50 meters

Figure 6:Jenson Brook wetland restoration project showing the existing ditch, 250 m of the 500 m local reference site (LRS), sampling locations and habitat features in the series of constructed ponds the ditch was diverted through.

Table 8: Biotic and abiotic variables measured in Jenson Brook routine monitoring program.

	Variable	Sampling Methods	See Sections
Fish	• Number of spawning adults • Species presence/absence • Catch-per-unit-effort by species and life history stage • Mean and maximum size of coho parr	• Spawner/Redd Counts (April and October) • Minnow Traps (April and August)	7.1.6.2 7.1.7.1 7.1.7.2 7.1.7.3
Macroinvertebrates	• Density • EPT index	• Surber sampler in riffles (April)	7.1.6.3 7.1.7.4
Periphyton	• Rapid survey of coverage and thickness	• Viewing bucket at points on transects through riffles (see Barbour et al. 1999; August)	7.1.6.4 7.1.7.5
Water quality	• Dissolved oxygen	• Meter readings at dawn (August)	7.1.6.5 7.1.7.6
Habitat Development	• Structural integrity • Compliance with design specifications	• Detailed habitat surveys at low flow (August)	

In the year prior to project construction the Streamkeepers also prepared a simple survey package consisting of a short questionnaire (section 7.1.9), a Jenson Brook fact sheet with a colour aerial photograph of the watershed on the back, and an invitation to a community meeting about Jenson Brook. Members of the group took the questionnaire door-to-door to households on properties through which the creek passed. They also arranged for the municipality to mail it out to all other property owners in the watershed. People who responded to the survey were given the fact sheet/aerial photograph. An article on the project was written for the local newspaper and printed alongside an announcement for the public meeting. At the meeting people were asked to fill out the questionnaire as they arrived. A biologist gave a short slide presentation about Jenson Brook and its fish community and then members of the Streamkeepers, gave a brief presentation about their restoration project. The meeting ended with an open discussion about the project and the creek. In the first, fifth and tenth year following project construction the process was repeated with the questionnaire modified slightly to reflect that the project had been constructed.

7.1.6 Monitoring Methods

7.1.6.1 Opinion Survey: Approximately the first quarter of the survey consisted of simple questions about properties and owners (see section 7.1.9). This allowed the Streamkeepers to characterize some important aspects of watershed residents and land use and was useful in exploring how factors such as length of residency and knowledge of the creek influenced other answers. The bulk of the questions explored awareness and opinions about the project, the group and trends and conditions in the stream. The last few questions were used to identify respondents that were interested in learning more or participating in projects in various ways.

7.1.6.2 Fish: Visual counts of spawners and redds were made from the bank each April (cutthroat trout, steelhead/rainbow trout) and October (coho salmon, chum salmon) by volunteers walking the length of all sites once weekly. The Streamkeepers also sampled the fish community on each site every spring and fall. Thirty minnow traps were set overnight at each site in an area approximately equal to that of the project. The group has 60 traps which allowed them to cover all four sites (project, LRS, DRS1 and DRS2) in two consecutive weekends. They measured the length of each salmonid caught and counted individuals of all species captured. They calculated the average number of fish per trap (catch-per-unit-effort; CPUE). This allows them to compare relative fish abundance (assumed to be reflected by CPUE), and lengths of fish in their project site with those of the natural off-channel habitats of the control sites using graphs.

7.1.6.3 Macroinvertebrates: Each April, four samples were taken from one of the riffles in the restoration project site and from riffles in the two reference sites using a surber sampler. The samples were preserved in 5% formalin. Later the number of mayflies, stoneflies and caddisflies and the total number of individuals in each sample were counted and recorded. The samples were stored in the event more detailed analysis is desired later.

7.1.6.4 Periphyton: Periphyton coverage was measured in the same riffles from which the macroinvertebrate samples were collected during August when flows are low and stable. The method described by Barbour et al. (1999) in which a bucket is modified to have a clear, plexiglas bottom marked with a 50-dot grid was used. At three locations on a transect (left bank, centre, right bank) the bucket was held in the water allowing a clear view of the bottom. The number of dots lying over macroalgae (long and filamentous) and over microalgae (coatings on rocks) were recorded. The length of the longest macroalgae strand and the thickness, in millimeters, of microalgae under each dot was also recorded.

7.1.6.5 Dissolved oxygen and temperature: Typically water temperatures are highest and dissolved oxygen lowest in mid to late summer in Jenson Brook and other streams in the area. DFO loaned a dissolved oxygen meter to the Streamkeepers every August during the monitoring period. They recorded dissolved oxygen concentration at the surface, and bottom of the largest pond just after dawn when levels are likely to be lowest. Temperatures were measured with a hand thermometer at the outlet to Jenson Brook during each site visit.

7.1.7 Results and Discussion

7.1.7.1 Spawner counts: Coho salmon spawning returns to the LRS remained at low, pre-construction levels for the first two years after the project was completed, but had increased five-fold to 52 fish by year five (Figure 7). In the tenth year 75 coho spawners were counted in the LRS. During this period, returns remained consistent but low at DRS1 and consistently high at DRS2. This suggests that the increase observed in the LRS was due to the project's influence rather than to larger scale factors such as improved ocean survival. Cutthroat trout showed a similar pattern of increase at the LRS, although some of this may have been due to other causes, as the numbers of spawners also increased slightly at both DRS1 and DRS2.

Chum salmon and steelhead spawner returns were relatively steady and showed the same year-to-year patterns at all three sites. Chum do not rear in freshwater, but typically emigrate to estuaries immediately after emergence (Salo 1991) and would not use the new wetland at all. Although steelhead juveniles would likely use the wetland, they are considered less dependant on off-channel habitat than are coho and cutthroat (Swales and Levings 1989) and may be limited by other factors.

7.1.7.2 Catch-per-unit-effort (CPUE): Trap catches of coho salmon and cutthroat trout increased nearly 10 fold in the restored wetland following a two-year time lag, but did not increase in either DRS1 or DRS2, suggesting a real increase in production due to the restoration (Figure 8). After five years densities of both species were approximately equal to those in DRS2 and were well above those of DRS1. Density of both species also increased somewhat in the LRS, suggesting that the positive effects of the restoration project spilled over into surrounding habitats. Steelhead and northern pikeminnow juveniles did not respond noticeably, and were higher in the mainstem habitat than in the wetland throughout the study.

Densities of threespine stickleback and redside shiners in the restoration site increased dramatically in the second year following construction but declined to near baseline levels in years five and ten. This transient response may have resulted from low predator density in the first two years as the new habitat was being colonized by adult cutthroat and resident rainbow trout. These fish are too large to enter minnow traps, so changes in their density were not captured in the monitoring program.

DRS1 had consistently lower densities of salmonids and higher densities of stickleback and redside shiners, than did DRS2. This finding mirrors the spawner count results, in which DRS1 returns were also consistently lower. Both reference sites are bordered by excellent spawning riffle, but differed in terms of water quality (see section 7.1.7.6).

7.1.7.3 Coho salmon size: Coho salmon juveniles typically disperse immediately after emerging from their redd in early spring to establish small feeding territories where they remain all summer (Sandercock 1991). Since Jenson Brook coho, like most coastal populations, remain in freshwater for a single year, only one age class is present in the stream during the August trapping. The mean size of juveniles in August can therefore be used as a rough index of their summer growth rates in different habitats.

These data for the restoration project site and the three reference sites over the ten-year, post-construction monitoring period are shown in Figure 9. In the first two years fish in the restoration project site were much larger than those in any of the reference sites, probably due to very high food availability. Low fish density (see section 7.1.7.2) and high in-stream productivity due to lack of shade from the immature riparian vegetation would both contribute to these conditions. The difference declined over time, as fish density and channel shading increased until restoration site coho were similar in size to those in the DRS2 reference site. Coho juveniles in the LRS and in DRS1 were much smaller throughout the monitoring period indicating that conditions were less ideal in these areas. Stronger currents, lower temperatures, poorer water quality, and reduced food availability are all possible reasons.

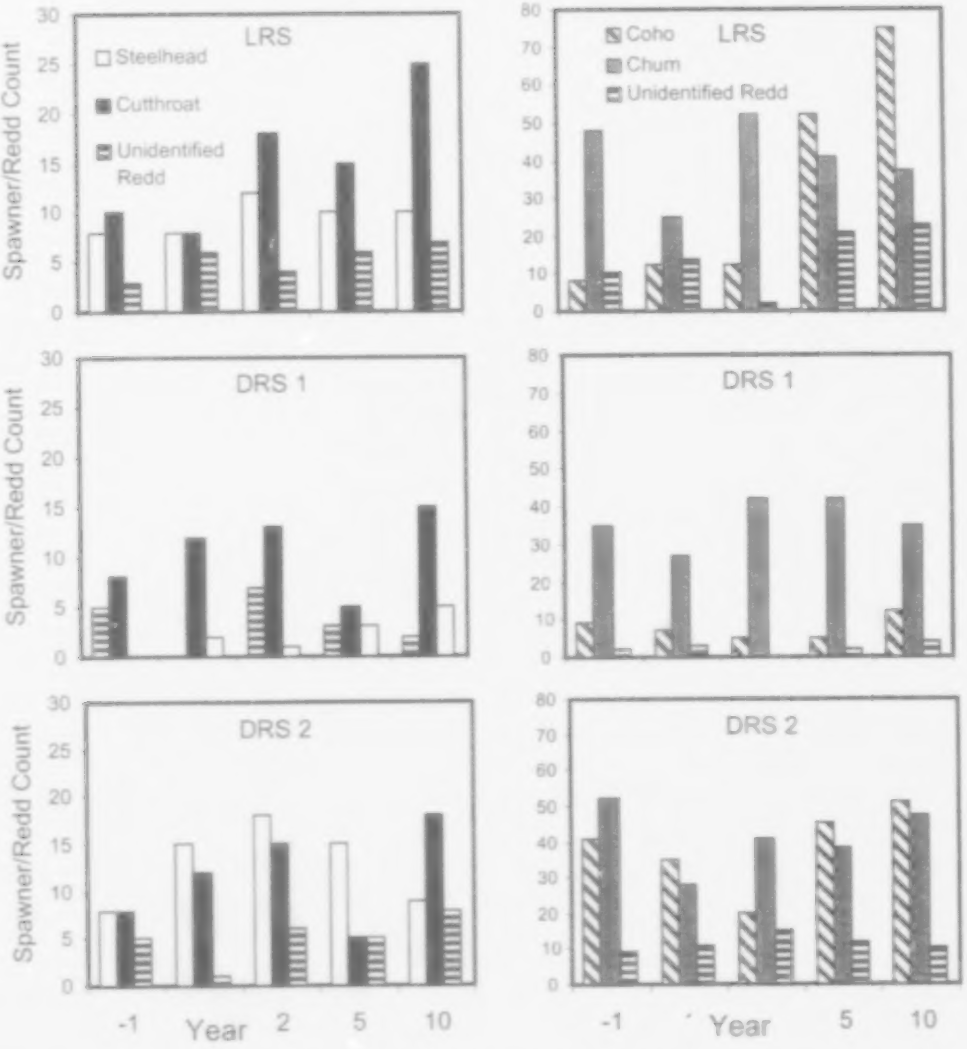

Figure 7: Visual counts of salmonids spawners and redds in 500 m sections of main stem habitat adjacent to the project site (LRS) and the two distant reference sites (DRS 1 and DRS 2). Monitoring extended one year prior to project construction and ten years after.

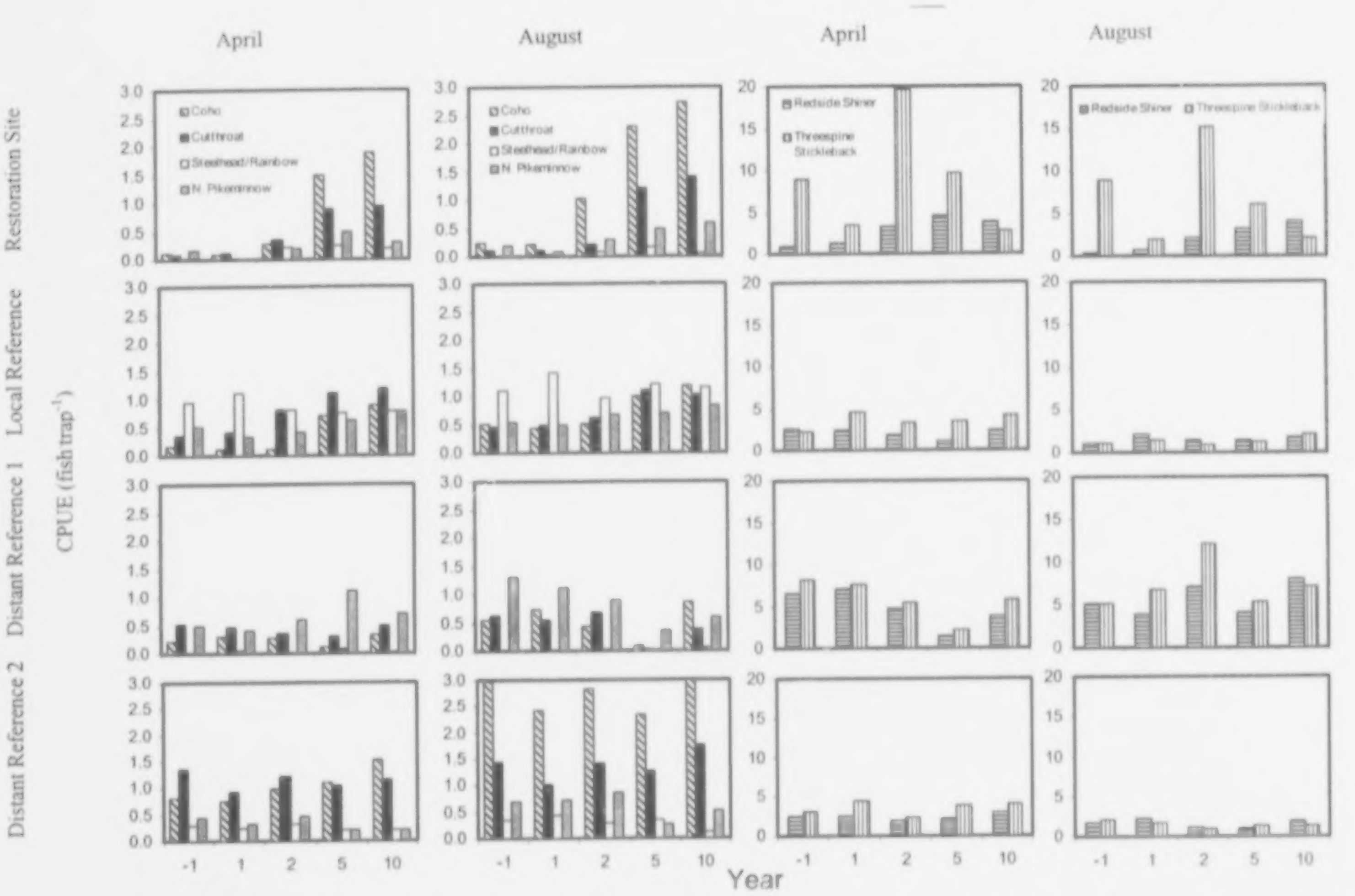

Figure 8: Average number of fish per trap in April and August sampling of the Jenson Brook wetland restoration project site and three reference sites. The local reference site is a 500 m section of the Jenson Brook mainstem adjacent to the wetland restoration. The two distant reference sites are natural off-channel wetland habitats. Sampling began one year prior to project construction (-1) and continued for ten years after construction. Pre-construction values at the project site describe catches in the channelized ditch (see Figure 6).

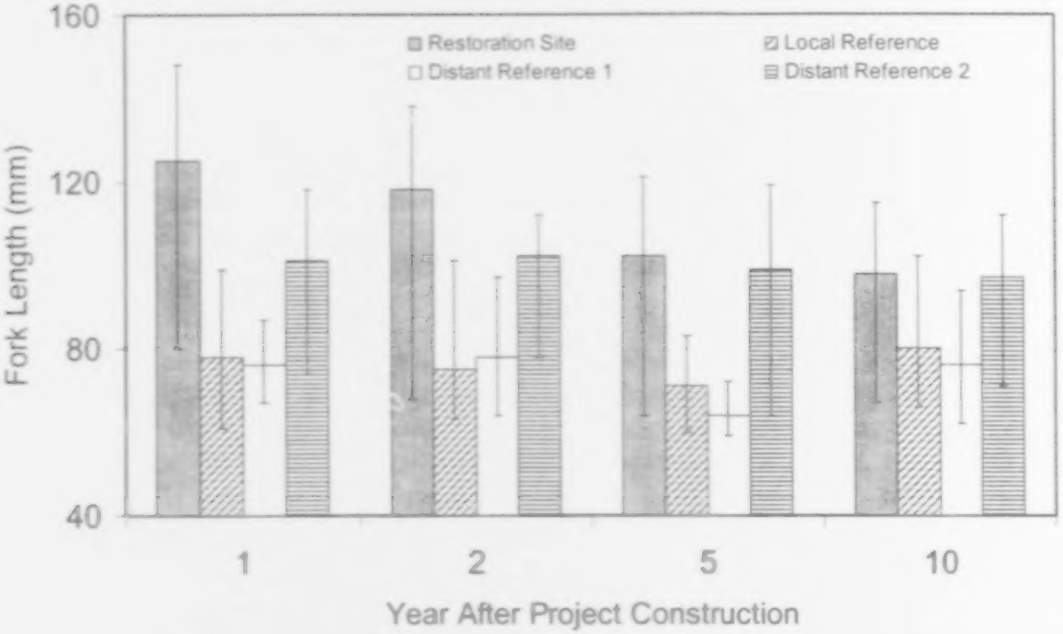

Figure 9: Mean length of coho salmon juveniles in August at the Jenson Brook restoration project site and three reference sites. Vertical lines indicate maximum and minimum values and numbers above bars indicate the number of fish caught.

7.1.7.4 Macroinvertebrates: Density and diversity of macroinvertebrates was much lower in the restoration site than in the reference sites in the first year following construction, but increased to levels similar to the local reference site and DRS2 by the second year after construction (Figure 10). DRS1 appeared to have consistently higher invertebrate densities, than the other sites, but had fewer taxa and a much lower proportion of mayflies, stoneflies and caddisflies (% EPT) than the other sites. This suggests that water quality at this site may be relatively low with the invertebrate community consisting of large numbers of a relatively few tolerant species.

7.1.7.5 Periphyton: Coverage of riffle cobbles in the restoration site by macroalgae was low in the first year and bloomed in the second year before returning to values similar to DRS2 (Figure 11). Microalgae coverage increased steadily over the 10 years of monitoring reaching values similar to the LRS and DRS1 within five years. According to field notes taken in year two, it was actually more developed than the coverage data indicates, but was partially masked by the overlying macroalgae bloom.

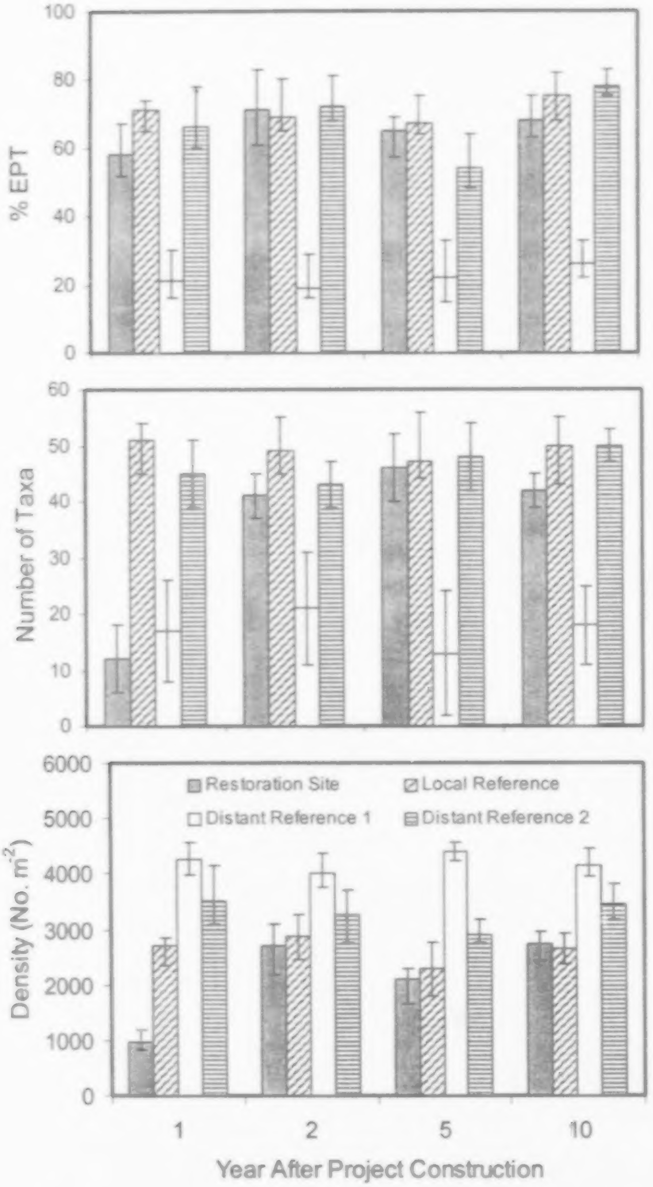

Figure 10: Macroinvertebrate density, diversity (number of taxa) and percent of taxa in the EPT families (Ephemeroptera, Plecoptera, Trichoptera) in riffles at the Jenson Brook restoration project site and three reference sites over a ten year post-construction monitoring period (mean ± range).

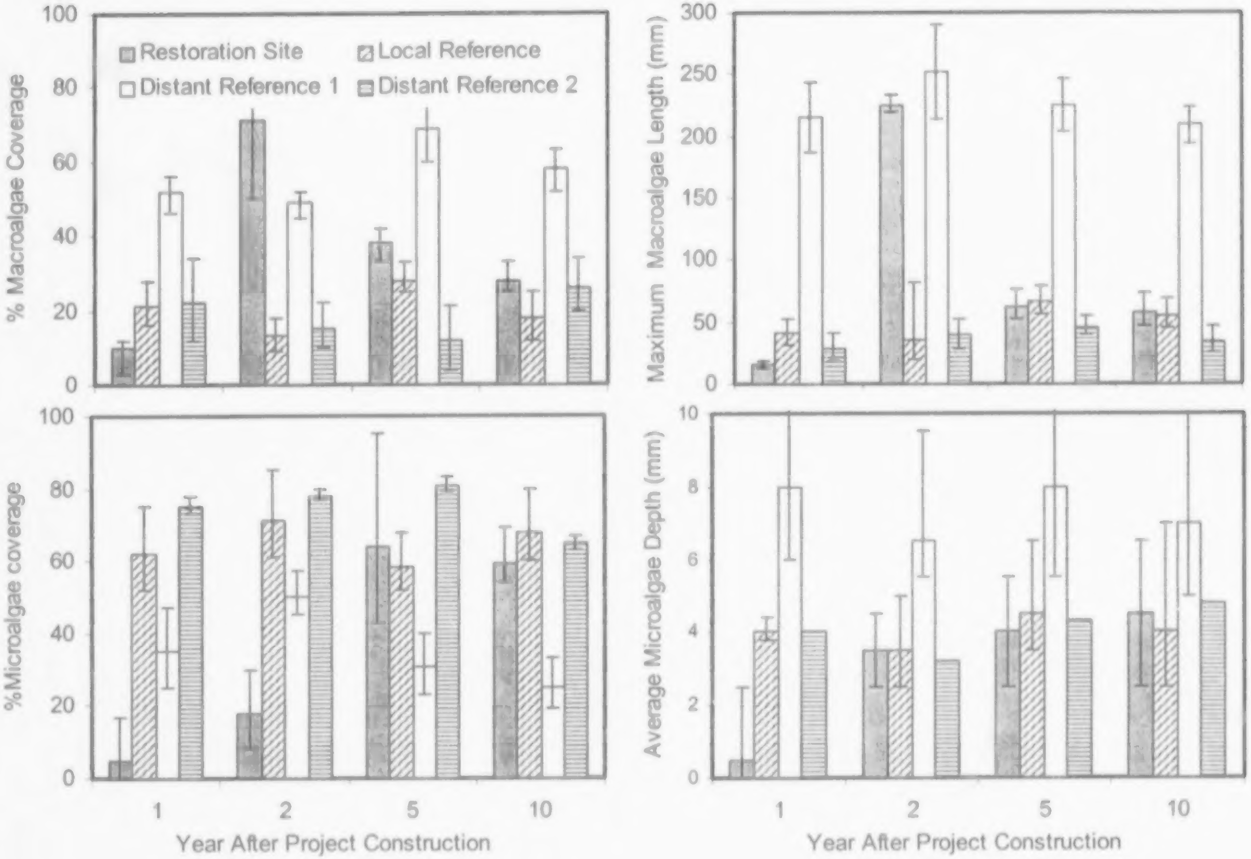

Figure 11: Periphyton coverage and development on cobble substrate in riffles at the Jenson Brook restoration project site and three reference sites over the ten years following project construction (mean ± range).

This is supported by the average depth in year two. DRS1 had consistently dense growth of macroalgae in August and combined macroalgae/microalgae coverages of near 100 percent, suggesting that nutrient loading may be a problem at the site.

7.1.7.6 Dissolved oxygen: Dissolved oxygen levels were above 5 mg·L^{-1} in the restoration project site on all occasions except at the bottom of pool 3 (P3) in year two when it dipped to 3 mg·L^{-1} (Figure 12). Although low, this level is unlikely to be lethal to fish as higher oxygen concentrations were available near the surface. The bloom of algae at the site at this time (see section 7.1.7.5) is likely responsible. Oxygen levels were consistently lower at DRS1, especially near the substrate where they were at lethal levels for most fish species. This is likely due to the persistent algal blooms at this site in August and explains the low diversity and paucity of EPT taxa in the macroinvertebrate community (see section 7.1.7.4) and probably accounts for the consistently low density of salmonids at the site (see section 7.1.7.2).

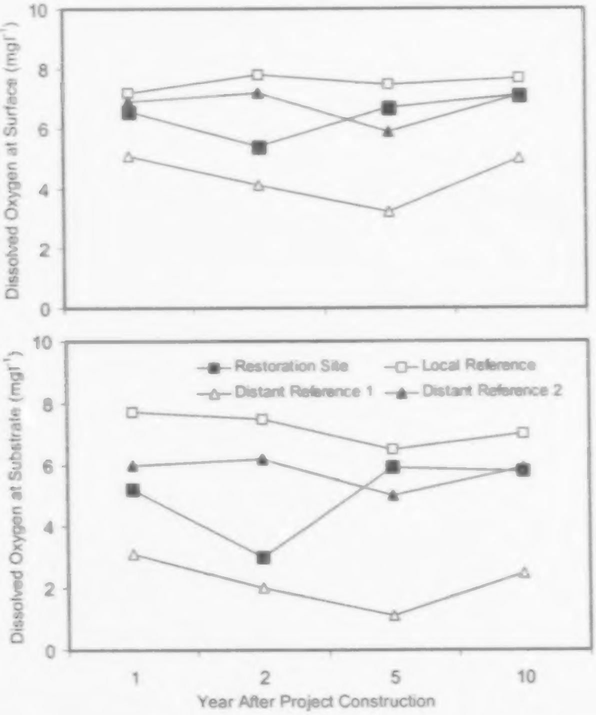

Figure 12: Dissolved oxygen concentrations at the surface and substrate of the deepest pools of the Jenson Brook restoration project site and three reference sites in August over the ten-year post-construction monitoring period.

7.1.7.7 Opinion Surveys: Analysis of survey results showed that 70% of the stream length passed through agricultural land and that livestock were not excluded from 22% of this (2.8 km). Although the creek flowed through over 90 properties, half of its length was contained on just 18 large parcels. A slight majority (53%) of landowners had resided on their property for more than ten years. These landowners had quite different responses to many of the opinion questions than did people who had resided on Jenson Brook for less than 3 years (Figure 13).

Awareness of the Jenson Brook Streamkeepers and of the restoration project rose steadily among all groups through the monitoring period. Awareness of the project was consistently higher than of the group especially among longer-term residents (Figure 13). Support for the project was high and steady among short and medium term residents. It was lower but rose through time among longer-term residents. Long-term residents, unsurprisingly, were consistently more aware of Jenson Brook and its fish community than short-term residents (Figure 14). Short-term residents appeared more likely than other groups to believe that Jenson Brook was in 'good health' or had 'improved within the last 10 years' around the time the restoration site was completed, but less likely than other groups to hold these opinions 10 years later (Figure 14). A major increase in medium and long-term residents' perception of stream health and recovery occurred between 1 and 5 years following project construction. In their answers to open-ended questions about stream health, many people linked their perceptions of improvement to direct sightings of fish and newspaper articles about increased salmon returns to the project area. The consistently different responses of new residents to many of the questions, with even more than ten years of JBS activity underlined the need for ongoing landowner education initiatives in the watershed.

7.1.8 Conclusions

On balance the monitoring results indicate that the Jenson Brook Wetland Restoration is a very successful project. Its coho salmon and cutthroat trout populations have increased to levels approaching those of a productive natural off-channel wetland (DRS2). Other indicators of habitat health including macroinvertebrate and periphyton community structure and dissolved oxygen levels are also very favourable. In addition there is evidence that its success has spilled over into adjacent habitats increasing populations there.

There are several cautionary lessons in the data as well. The restoration site exhibited major transient changes in a number of indicator variables in year 2 (oxygen, periphyton, fish community structure) which emphasize the need for relatively long term monitoring. One of the reference sites (DRS1) became seriously oxygen depleted in late summer and this appeared to alter the biotic community, limiting its usefulness in comparisons and underlining the 'insurance' benefit of including more than one reference site in the study.

Lastly, JBS activities appear to have had a remarkably positive influence on the local community with respect to awareness of Jenson Brook and its fish population. Part of this was undoubtedly due to the real positive impact the project had on the stream, but JBS members attribute much more of the social impact to the process of conducting the survey: knocking on doors and talking to residents every few years about their creek. In the process they also learned a great deal about the watershed and have identified a number of sites for which they are developing additional projects.

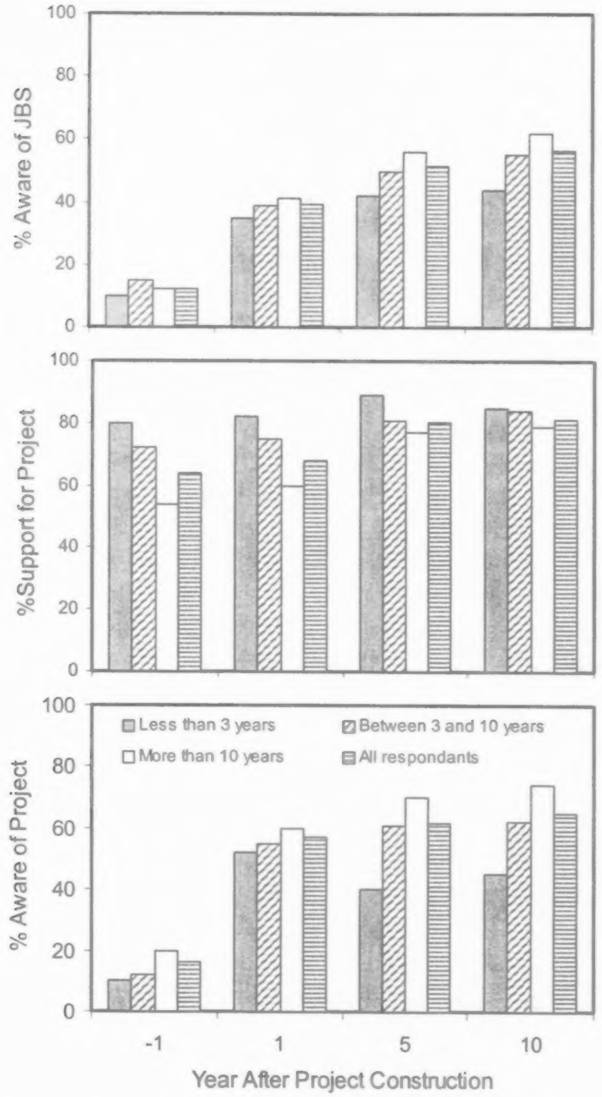

Figure 13: Proportion of survey respondents that were aware of the restoration project (bottom panel), supported the project (middle panel) and were aware of the Jenson Brook Streamkeepers (JBS; top panel) in the year before and at one, five, and ten years following project construction. Respondents are divided into groups based on the length of time they have resided in the watershed. Only riparian landowners are included.

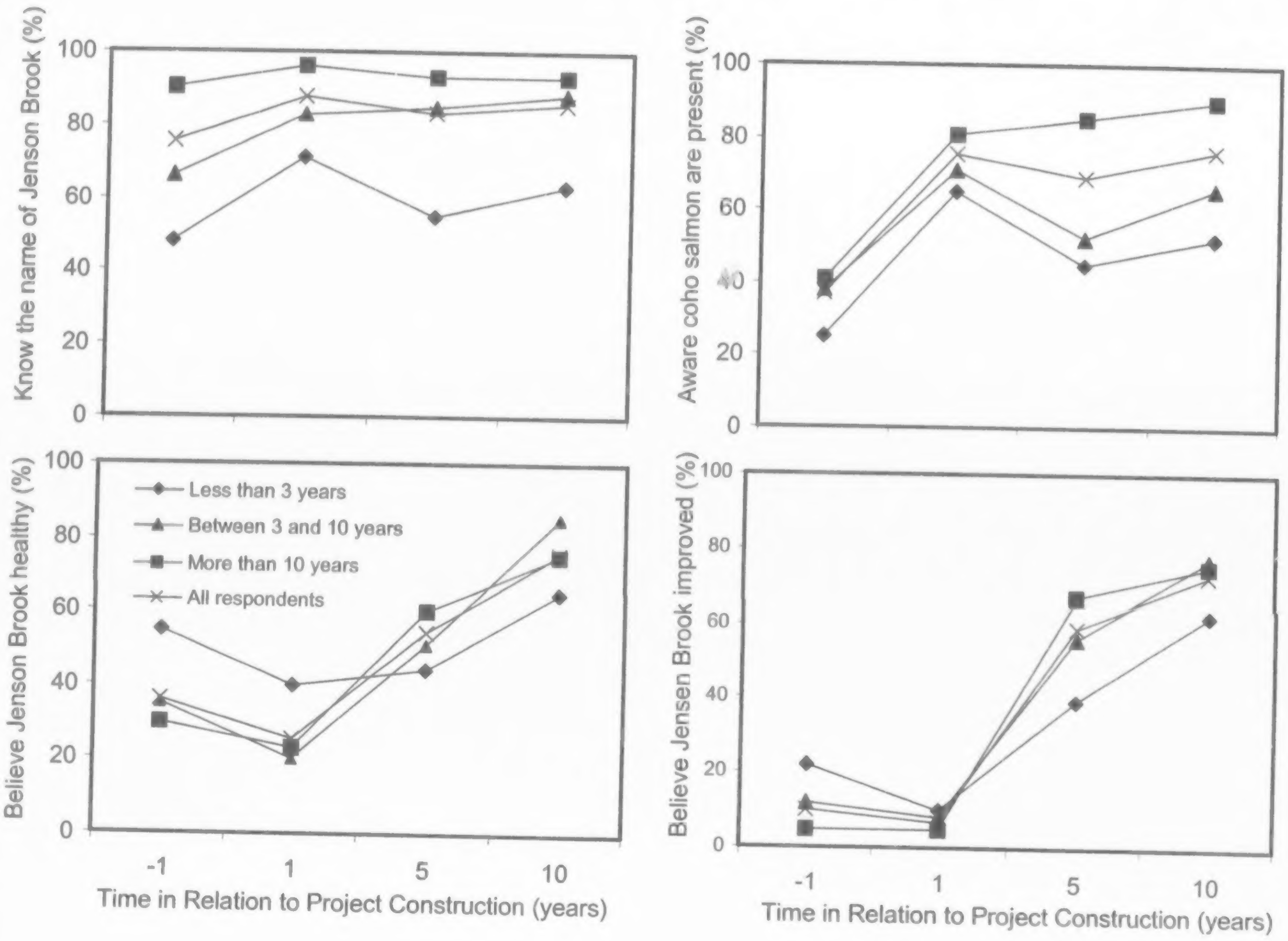

Figure 14: Indices of awareness and perception of Jenson Brook among riparian property owners who have resided in the watershed for different lengths of time.

7.1.9 Landowner Survey

Name of Resident ______________________________ Date ____________

Email: ______________________________ Phone ____________________

Address/Location ____

____

____

____

Year Moved to Property __________

Landowner
If Different ______________________________ Phone __________

Property Size ______________ Length of Creek on Property __________

Main Land Uses ____

Septic Tank ☐ Date Last Pumped ________ Pump From Creek ☐

Livestock Access ☐ Number of Livestock ________

****

What is the name of the creek on your property?

____

Would you say you know the creek on your property:
very well ☐ reasonably well ☐ or not well at all ☐?

What species of fish live in the creek?

____

Would you say that the abundance of these fish has increased, decreased or stayed the same in the past 10 years? __________

What do you think the reasons are for this change?

____

____

____

Would you describe the health of the creek on your property as:
excellent ☐ good☐ fair☐ poor ☐ or very poor ☐

Why do you say that?

____

____

____

____

Has the overall health of the creek improved, stayed the same or become worse in the last 10 years? ____________________________

What do you think has caused these changes?

____

____

____

____

Please rate the following factors in terms of how you perceive their level of threat to the health of Jenson Brook.

a. Dredging and Channelization
Very threatening ☐ Somewhat threatening ☐ Mildly threatening ☐ No threat ☐

b. Litter and garbage
Very threatening ☐ Somewhat threatening ☐ Mildly threatening ☐ No threat ☐

c. Introduced species
Very threatening ☐ Somewhat threatening ☐ Mildly threatening ☐ No threat ☐

d. Over fertilization
Very threatening ☐ Somewhat threatening ☐ Mildly threatening ☐ No threat ☐

e. Urbanization
Very threatening ☐ Somewhat threatening ☐ Mildly threatening ☐ No threat ☐

f. Erosion and sedimentation
Very threatening ☐ Somewhat threatening ☐ Mildly threatening ☐ No threat ☐

g. Water withdrawals
Very threatening ☐ Somewhat threatening ☐ Mildly threatening ☐ No threat ☐

h. Other_______________
Very threatening ☐ Somewhat threatening ☐ Mildly threatening ☐ No threat ☐

Have you ever heard of the Jenson Brook Streamkeepers?

yes ☐ no ☐

Where did you hear of them? ________________________________

Are you aware of the proposed Jenson Brook Wetland Restoration Project? _______

Where did you hear of it? ________________________________

Can you describe it for me? ________________________________

____

____

Do you support this project? ____________

Why or why not?

____

____

____

____

Do you support community based fish and wildlife habitat restoration in general?

____

"These projects should receive public funding to match community contributions of materials, time and money." Do you agree or disagree? ____________________

Why?____

____

____

Would you be interested in:

☐ being informed of an information and discussion meeting about Jenson Brook which would involve other landowners, biologists and representatives of government agencies and industrial landholders?

☐ being informed of volunteer activities such as tree planting and fish habitat restoration, aimed at restoring the watershed?

☐ discussing opportunities for improving the habitat value of the creek on your property with a biologist?

☐ making a contribution of materials or equipment time to the wetland restoration project?

7.2 CASE STUDY 2: BIG TROUT RIVER SAWMILL EXPANSION

7.2.1 Site and Project History

Northern Forestry Inc. (NFI) has received approval to expand it's sawmill on the Big Trout River a few kilometers downstream of Big Trout Lake. The project will involve in-filling a 140 m section of the river (HADD site; area = 2,700 m^2). In addition 6,360 m^2 of riparian vegetation will be destroyed. DFO staff stipulated that a like-for-like habitat compensation project be completed on the property as a condition of authorization. Compensation ratios for in-stream habitat and riparian areas are to be 1.2:1 and 1:1, respectively.

NFI has retained a reputable local consulting firm to design the project, provide environmental monitoring during construction and to monitor the project after it is built. The consultants searched provincial and federal databases and spoke with federal and provincial biologists to characterize the Big Trout River (Table 9). The species of primary management interest are the rainbow trout, kokanee salmon, chinook salmon and chiselmouth. The chinook supports an aboriginal food fishery. The kokanee and rainbow populations supports sport fisheries important to local anglers and tourism. The chiselmouth is locally rare and has a small and fragmented distribution. It is blue listed (a species of special concern) by the provincial Conservation Data Centre, but is not listed under the federal Species at Risk Act.

Table 9: The fish community of the Big Trout River.

Family	Species	Common Name	Life Stage
Salmonidae	Oncorhynchus tshawytscha	Chinook salmon	Spawning and rearing
	Oncorhynchus nerka	Kokanee	Spawning only
	Oncorhynchus mykiss	Rainbow trout	All life stages
	Prosopium williamsoni	Mountain whitefish	All life stages
Cyprinidae	Ptchocheilus oregonensis	Northern pikeminnow	All life stages
	Richardsonius balteatus	Redside shiner	All life stages
	Mylocheilus caurinus	Peamouth	All life stages
	Acrocheilus alutaceus	Chiselmouth	All life stages
	Rhinichthys cataractae	Longnose dace	All life stages
	Rhinichthys falcatus	Leopard dace	All life stages
Catostomidae	Catostomus catostomus	Longnose sucker	All life stages
	Catostomus columbianus	Bridgelip sucker	All life stages

Maximum summer temperatures in the HADD site are known to be close to the upper limits for salmonids due to the warming that occurs in the lake immediately upstream of the site. There is a concern that temperatures in the new habitat will be even higher during the first few years, before the riparian vegetation is large enough to provide significant shade. Consequently temperature monitoring will be part of the project.

7.2.2 Project Objective

Achieve a net gain in productive capacity of habitat for the combined fish community and individually for rainbow trout, kokanee, chinook salmon and chiselmouth.

7.2.3 Project Design

The approved design consists of a 3,240 m^2 channel diversion surrounded by 6,360 m^2 of riparian plantings (Figure 15). Habitat complexing in the channel consists of a constructed undercut bank, anchored root-wads and boulder clusters. These are intended to provide cover for larger fish, particularly adult rainbow trout. Clusters of large boulders and rock wing deflectors will concentrate and direct flows to maintain pool depths and provide substrate for the periphyton which adult chiselmouth forage on. The channel is lined to a depth of 30 cm with washed gravel held in place by a number of rock weirs. This is intended to provide spawning habitat for all species. An overflow channel cuts across one of the meanders. Although it is not expected to contain flow during periods of low water, it will provide an off-channel refuge for fish during high discharge events. An old berm will be removed to restore fish access to an existing backwater area that is expected to provide good summer rearing habitat for some of the cyprinids, catostomids and an additional off-channel refuge for all species.

7.2.4 Monitoring and Assessment Goals

Assess net change in productive capacity of the compensation site relative to the HADD site using a range of biotic and abiotic indicator variables.

7.2.5 Monitoring Program

7.2.5.1 Experimental Design: A before-after-control-impact-paired (BACIP) experimental design with spatially nested control sites is applied to the biological variables (Table 10). Monitoring starts two years prior to construction and resumes when construction is completed. In the post construction period, monitoring occurs in years 1, 2, 5, 6, 9 and 10. This allows net changes in variables to be statistically assessed immediately after (years 1 and 2), in the short term (years 5 and 6) and in the medium term (years 9 and 10) following project construction. The site is sampled three times annually, in April, July and October in both the pre and post-monitoring periods. See section 5.4 for details on experimental design.

An as-built survey is conducted in the first year following construction and confirms that the project meets the area requirements and design specifications of the project. Here we will assume that site integrity and the condition of physical habitat within the stream remains acceptable throughout the monitoring period and focus our attention on assessing its productive capacity.

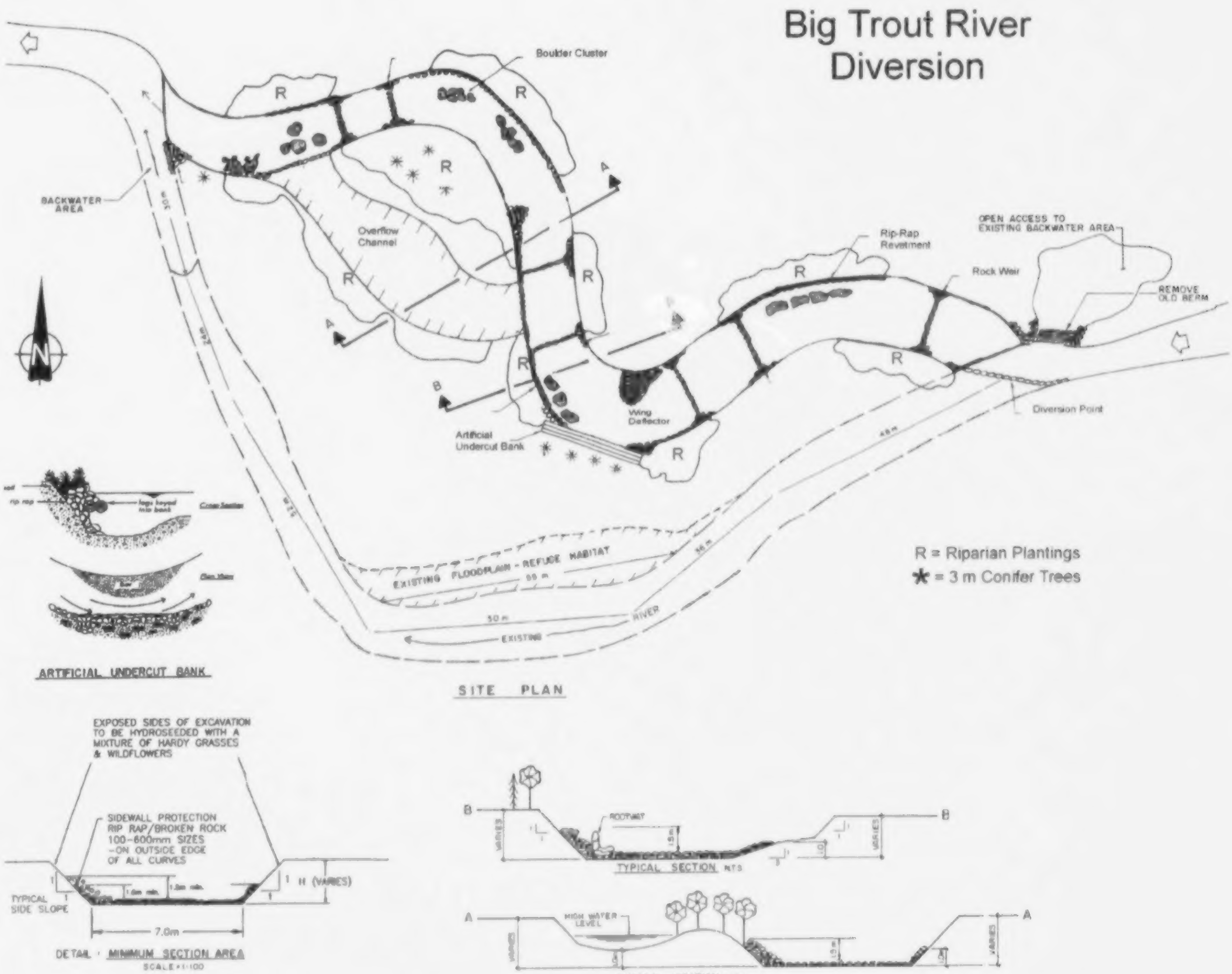
Big Trout River
Diversion
Boulder Cluster
R
BACKWATER AREA
Overflow Channel
A
B
Artificial Undercut Bank
Wing Deflector
Rip-Rap Revetment
Rock Weir
OPEN ACCESS TO EXISTING BACKWATER AREA
REMOVE OLD BERM
Diversion Point
EXISTING FLOODPLAIN - REFUGE HABITAT
50 m
EXISTING
RIVER
R = Riparian Plantings
✱ = 3 m Conifer Trees
sod
rip rap
logs keyed into bank
Cross Section
Plan View
ARTIFICIAL UNDERCUT BANK
SITE PLAN
EXPOSED SIDES OF EXCAVATION TO BE HYDROSEEDED WITH A MIXTURE OF HARDY GRASSES & WILDFLOWERS
SIDEWALL PROTECTION RIP RAP/BROKEN ROCK 100-600mm SIZES -ON OUTSIDE EDGE OF ALL CURVES
TYPICAL SIDE SLOPE
1.0m min.
1.2m min.
H (VARIES)
7.0m
DETAIL · MINIMUM SECTION AREA
SCALE 1:100
ROOTWAD
VARIES
1.5m
1.0
TYPICAL SECTION NTS
HIGH WATER LEVEL
1.5m
1.2
TYPICAL SECTION NTS

Figure 15: Construction drawings of Big Trout River Diversion project.

Table 10: Biotic and abiotic variables measured in the Big Trout River compensation project monitoring program. Channel unit numbers refer to Figure 17.

	Variable	Sampling Methods

Fish	• Spawner/redd counts
	• Biomass and density
	  • Total
	  • By species and life stage
		• Spawner/redd counts (April and October)
		• Backpack electroshocker (three pass removal from 10 m section of each channel unit)
		• Minnow trap (10 sets per channel unit; only when too deep for electrofishing i.e. P3a, P3b, BW2a)
		• Gillnet (four 15 minute sets per channel unit; only when too deep for electrofishing)

	• Movement • Growth rates • Condition	• Pitt tag adult rainbow trout, chiselmouth, northern pikeminnow, longnose sucker and bridgelip sucker and juvenile chinook salmon when captured
Macroinvertebrates	• Density • EPT index • Taxa richness	• Hess sampler in riffles (four replicates in R1 and R3 of each site)
Periphyton	• Rapid coverage and thickness survey	• Viewing bucket at points on transects through R1 and R3
	• Biomass • Total number genera • Shannon diversity index for diatoms	• Scraped samples from riffle cobble in R1 and R3
Riparian (July only)	• Tree and shrub density • Vegetation cover	• Band transects (Figure 25) • Modified spherical densiometer readings from mid-channel on transects (Figure 25)
Water Temperature	• Maximum annual temperature • Mean daily fluctuation in July • Degree days above 18 °C	• Temperature loggers (in first riffles upstream and downstream of project site; see Figure 26)

Two distant control sites are established in the watershed. DCS1 is on a major tributary that enters the Big Trout River 10.3 km downstream of the project site (Figure 16). DCS2 is on the Big Trout River a further 15.5 km downstream. They are fairly similar in character to the project site in terms of size, gradient, and location downstream of a kokanee bearing lake and are readily accessible by road. The locations, downstream from lakes, one on a separate tributary and the other significantly downstream from the project site were chosen to ensure that events at the project site do not influence them.

A local control site is established in the 140 m section of Big Trout Creek immediately upstream of the project site. Only fish are monitored at this site as it is intended to establish whether changes in the fish community observed in the project site are due to immigration from surrounding habitats rather than on-site production.

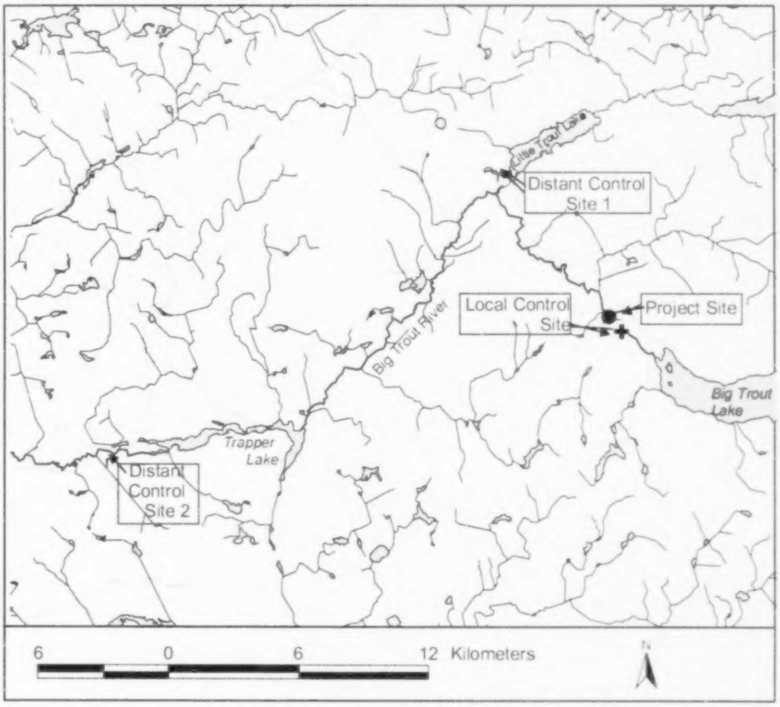
Little Trout Lake
Distant Control Site 1
Local Control Site
Project Site
Big Trout River
Big Trout Lake
Trapper Lake
Distant Control Site 2
6
0
6
12 Kilometers
N

Figure 16: Locations of project and control sites for the Big Trout River monitoring study. The local control site is immediately upstream of the project site. Distant control site 1 is located on a separate tributary 10.3 km from the project and distant control site 2 is located on the Big Trout River 25.8 km downstream of the project site. All are similar in character and are situated short distances downstream of kokanee bearing lakes.

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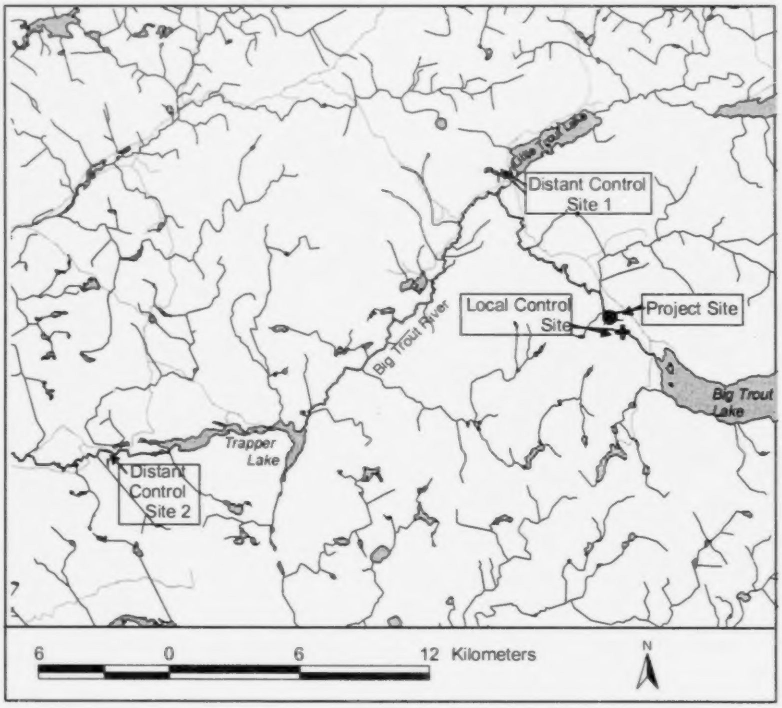
Little Trout Lake
Distant Control Site 1
Local Control Site
Project Site
Big Trout River
Big Trout Lake
Trapper Lake
Distant Control Site 2
6
0
6
12 Kilometers
N

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7.2.6 Monitoring Methods

Channel unit configurations and other habitat details of the pre and post-construction project site are shown in Figure 17. Sampling locations within the sites are given in Table 10. The three control sites were sampled in a similar manner although detailed maps are not included here for reasons of brevity. Values of the two distant control sites were averaged for calculations of NNL.

7.2.6.1 Area Verification and NNL Calculation: The project site was surveyed by a professional crew to measure area by habitat type, as built. These measurements were used to calculate the *actual* compensation ratio, for assessment of NNL (see section 5.4.9 for details on calculations).

7.2.6.2 Fish: Visual counts of spawners and redds were conducted in April (rainbow trout) and October (chinook and kokanee salmon) by walking the shoreline daily during the sampling period.

Fish sampling is stratified by habitat type. In this case all channel units were sampled because there were few units overall. If the project had been larger, representative channel units of each habitat type would have been selected systematically (e.g. every 2nd riffle). Shallow habitats were sampled using a 3-pass removal protocol using a backpack electroshocker in a 10 m section of channel unit, which was isolated with stop-nets. Deep pool habitats that could not be effectively sampled by electroshocking were sampled using baited minnow traps and/or multi-panel experimental gill nets (0.5-3.5 inch mesh). In these cases sampling occurs on three consecutive days. All captured fish were marked by fin clipping, and abundance for each habitat type and for each species and life stage was estimated using a Petersen mark-recapture study design (Krebs 1989). Density was calculated by dividing abundance by sampled area. Biomass was calculated by dividing mean individual weight by the total area of each habitat type in the site. Each parameter was then expanded by the compensation ratio therefore taking into account the difference in habitat area.

All adult fish were weighed (nearest 0.1 g) and measured (fork length, nearest mm). Juveniles were processed similarly, but subsampled (n=30 per species) when large numbers were captured. Selected species were marked with pit tags (adult rainbow trout, suckers, chiselmouth, northern pikeminnow; and juvenile chinook salmon) to allow monitoring of growth and movement between sampling periods. Relative weight, a length corrected measure of condition (Anderson and Neumann 1996), was calculated for all species and life stages.

7.2.6.3 Macroinvertebrates: Four replicate samples in each of two riffles per site were collected using a Hess sampler and preserved in 5% formalin. Sampling proceeded from downstream to upstream. Samples were sorted and invertebrates were identified to genus or species in the laboratory. Total taxa richness, total density, and percentage of organisms in the mayfly (Ephemeroptera), stonefly (Plecoptera) and caddisfly (Trichoptera) families were calculated. Density estimates were expanded by the compensation ratio. Samples were archived in case more detailed future analyses are required.

7.2.6.4 Periphyton: A rapid coverage and thickness survey was conducted as described in section 7.1.6.4. In addition, biomass was measured (as ash free dry mass, AFDM) and the total number of macroalgae and diatom species, and the Shannon diversity index for diatoms were calculated. Biomass samples were obtained by scraping periphyton from riffle cobbles in four replicate 0.09 m^2 samples (i.e. standard Hess sampler size). Two additional samples were collected and used to identify macroalgae and diatoms to species.

7.2.6.5 Riparian vegetation: Ten permanent transects were established at regular intervals along each bank. The transects extended perpendicularly from 10 m from the top of each bank or to the edge of the riparian vegetation (Figure 18). The number of living and dead trees and shrubs within 1 m of the transect line is recorded. Diameter at breast height (dbh) is recorded by species for live trees within the transect. Mean tree density, mean shrub density, mean dbh by species, and percent mortality by species are calculated (see section 7.2.7). Canopy closure is estimated from the centre of the channel on each transect using a modified spherical densiometer (Mills and Stevenson 1999).

7.2.6.6 Water temperature: Temperature loggers were set in shaded riffles immediately upstream and downstream of the diversion points at the beginning of the pre-project monitoring phase. One additional logger was set in the middle of each distant control site reach (Figure 17). All were programmed to record temperature hourly and data was downloaded annually. With some minor differences all sites are very similar thermally. The distant control sites were not used further in the analysis; rather the upstream logger at the project site is considered the control site and the downstream station considered the impact site in the BACIP design, as the temperature difference between the stations is a direct measure of the site's impact on stream temperature. Variables analyzed are maximum annual temperature, degree-days over 18 ^{o}C, and mean daily fluctuation in July.

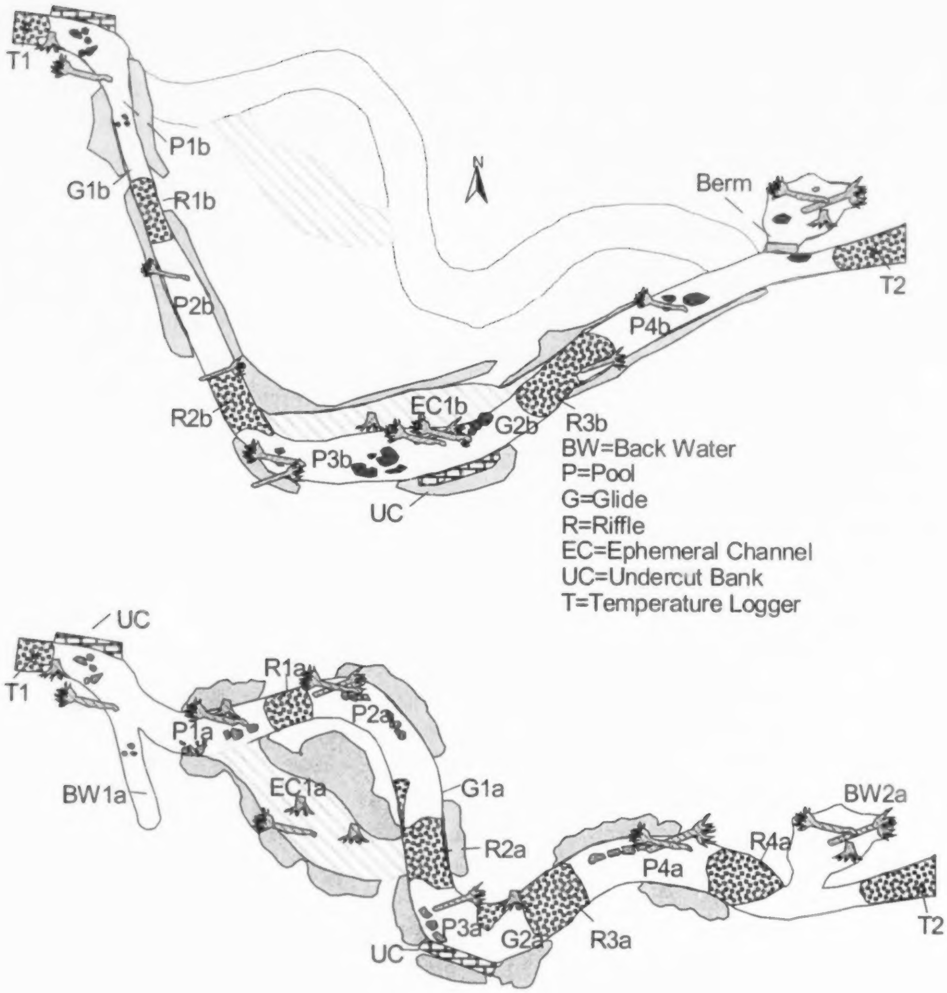
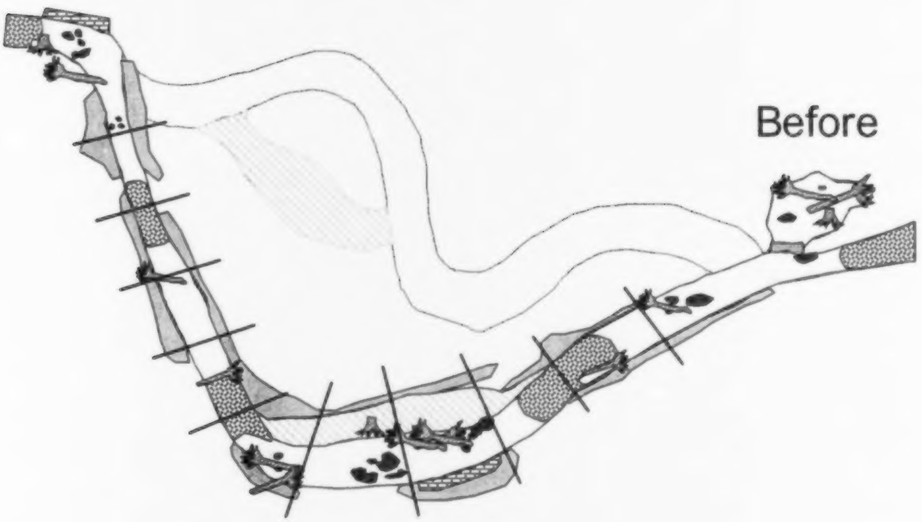

T1
P1b
G1b
R1b
N
Berm
T2
P2b
P4b
R2b
EC1b
G2b
R3b
P3b
UC
BW=Back Water
P=Pool
G=Glide
R=Riffle
EC=Ephemeral Channel
UC=Undercut Bank
T=Temperature Logger
UC
T1
R1a
P2a
P1a
BW1a
EC1a
G1a
R2a
BW2a
R4a
P4a
P3a
G2a
R3a
UC
T2

Figure 17: Channel units and habitat features of the Big Trout River project site before (top) and after (bottom) construction. Channel units are numbered from the downstream end of the sites.



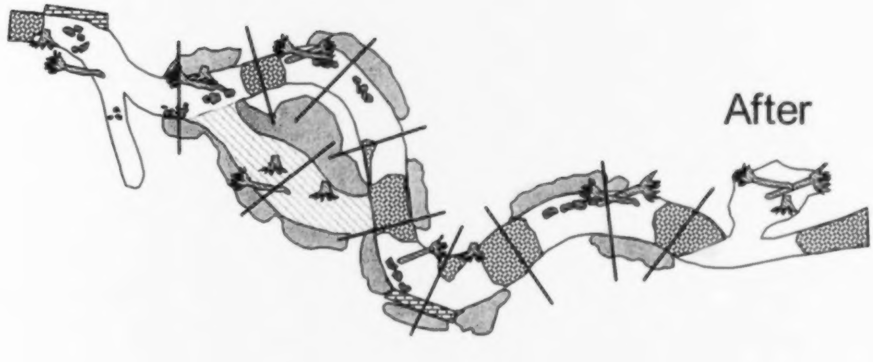


Figure 18: Location of vegetation transects at the project site before and after construction. The restoration project is sketched in to the before drawing for orientation purposes. Transects are perpendicular to the channel and extend 10 m from top of bank.

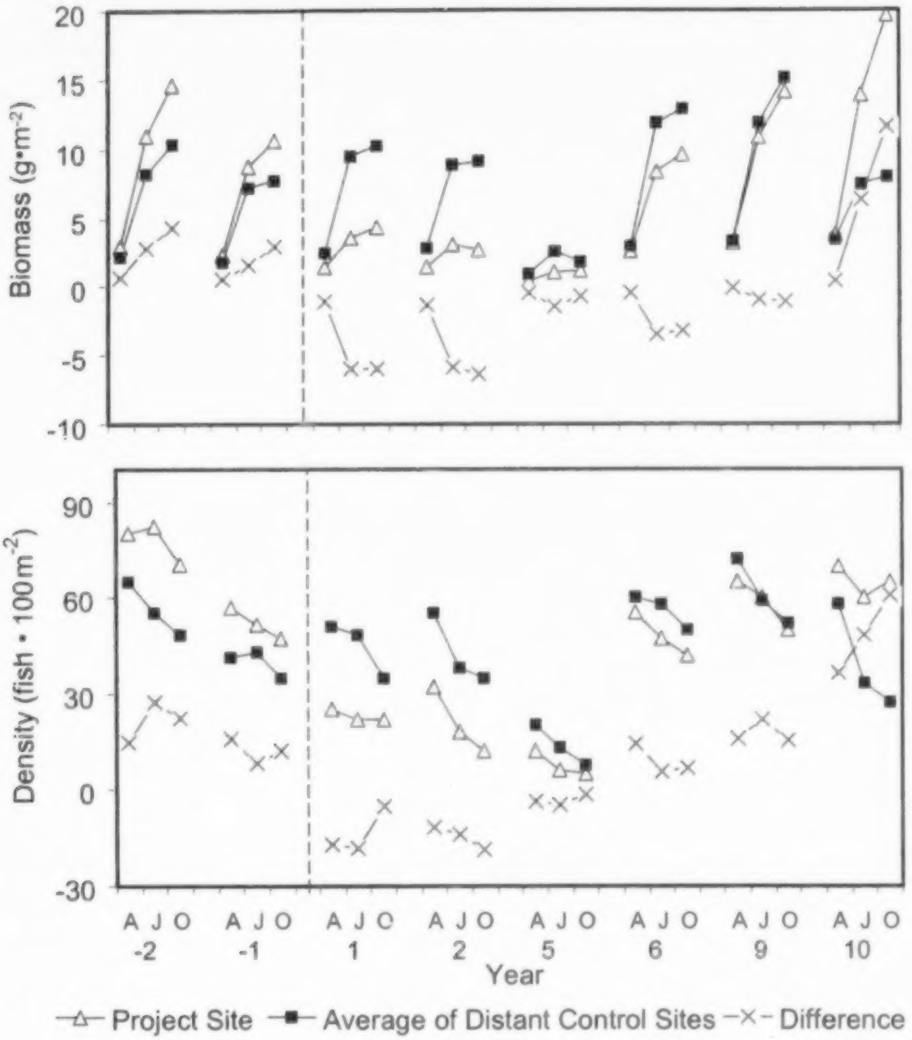
7.2.7 Results and Discussion

7.2.7.1 Area Verification and NNL Calculation: A survey of the HADD site revealed that the area of riparian zone destroyed closely matched 6,360 m^2 listed in the authorization. The area actually replanted in compensation was slightly larger at 6,800 m^2, producing an actual compensation ratio of 1.07: 1. The area of in-channel habitat actually destroyed in the HADD was less than that authorized at 2,400 m^2 rather than 2,700 m^2. The area of in-channel habitat created at the compensation sites closely conformed to the 3,240 m^2 required in the authorization and to the proportions of pool and riffle habitat in the design. This gave an actual compensation ratio of 1.35:1, well in excess of the 1.2:1 required.

In net change calculations, outcomes were obtained by multiplying area-specific parameters (e.g. g/m^2) by the actual compensation ratio to take into account the difference in impacted versus compensated area. As detailed above, this is 1.07:1 for riparian habitat, and 1.35:1 for in-channel measures. Parameters not expressed in area-specific terms are not expanded, but are important to detail the range of potential habitat changes and are used as weight of evidence to support NNL determinations (see section 5.4.9).

7.2.7.2 Fish: Total fish density and biomass (not shown) were significantly reduced for at least six years following construction in the project site relative to the distant control sites (average of DCS 1 and DCS2). NNL was achieved by the final two years of the ten-year post-construction monitoring period. Biomass of juvenile chinook salmon (Figure 19) showed similar patterns. Year-to-year variation in density is high at both the control and project sites, but the paired design factors this out by using the difference between sites rather than absolute numbers (e.g. years 5 and 6).

A closer look at some of the other individual species reveals several other variants on the overall trend and sheds light on some of the strengths and constraints of the BACIP design. The number of kokanee spawners (not shown) demonstrated NNL even in the first two years following construction, probably because the new riffles provided excellent spawning habitat and the compensation ratio meant that more habitat area was created than destroyed by the construction. The chiselmouth response to the project was complex and depended upon the scale at which it was measured (Figure 20). Density at the project site actually increased relative to the distant control sites and remained elevated for six years following project construction. Relative to the local control site, however, the trend was opposite. At the local control site, density declined suggesting that chiselmouth simply migrated into the project site from nearby habitats, but were not replaced in the habitats they vacated. The population within the reach was simply redistributed. When this was accounted for statistically, a detectable decrease was revealed that persisted throughout the monitoring period.



	Density			Biomass		
Year	**1-2**	**5-6**	**9-10**	**1-2**	**5-6**	**9-10**
D_A-D_B	-30.93	-14.00	16.34	-6.55	-3.78	0.58
SE	3.48	4.10	8.09	1.17	0.82	2.19
t	-8.89	-3.42	2.02	-5.60	-4.59	0.27
p	<0.0001	0.0065	0.071	0.0002	0.0010	0.7927
Outcome	**NL**	**NL**	**NNL**	**NL**	**NL**	**NNL**

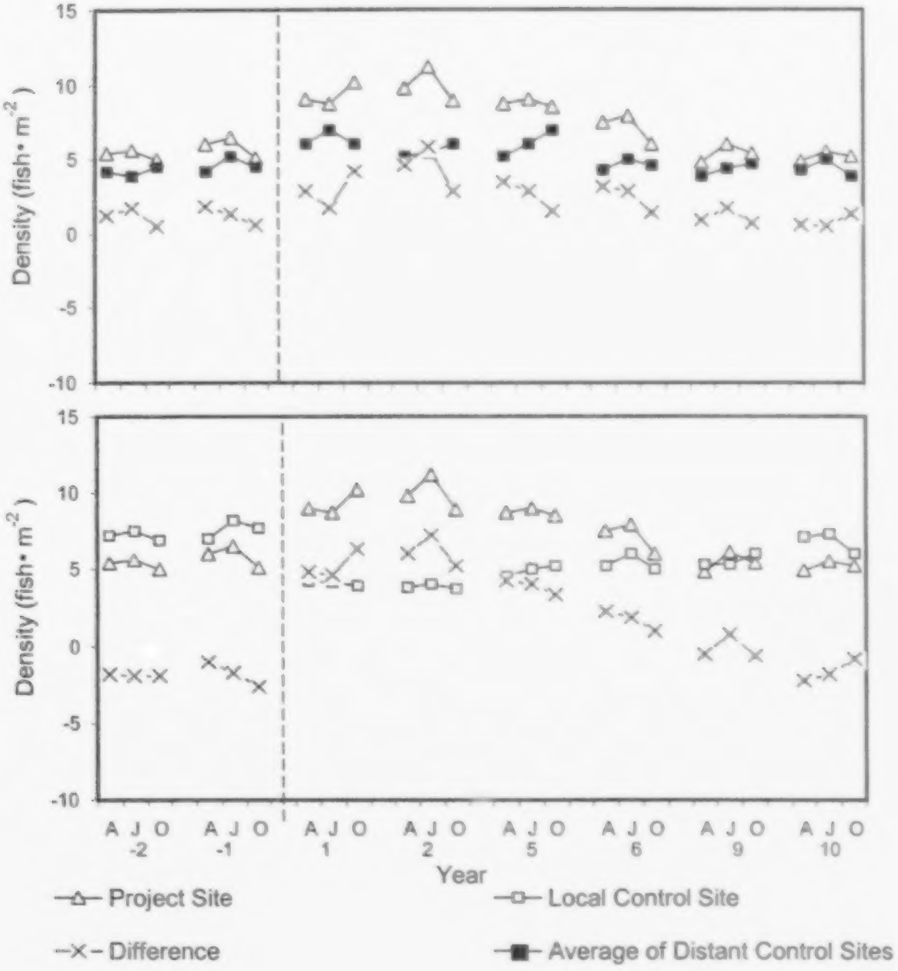
Figure 19: Density and biomass of juvenile chinook salmon (*Oncorhynchus tshawytscha*) at the project site and the control sites (A=April, J=July, O=October). Vertical dashed line indicates time of project construction. T-tests (2-tailed, df=10, t_{crit} = 2.228) compare the mean difference between the sites in each of three post-construction periods (years 1-2, 5-6 and 9-10) to the pre-construction period. P-values indicate significance. Of the significant results, t-values indicate the direction of change. There is a significant change in both density and biomass (a net loss) in the immediate and short term monitoring periods, but by years 9 and 10 there is no significant difference and no net loss is detected.

There appears to be a net loss of rainbow trout biomass from the project site (Figure 21) although the ability to detect it depended upon sampling effort and/or the level of statistical certainty required in identifying a significant effect. In the lower panel all channel units were sampled by three-pass electrofishing, and the variation within and among years is very high. This leads to a NNL conclusion after year 5. However, in research work the probability of finding a statistically significant effect where none really exists (alpha, type 1 error) is customarily set at 5% (p=0.05), but high variability or inadequate sample size can make a type II error (failing to detect an effect when in fact one exists) more likely. In this case if alpha is relaxed to 10% (p=0.100), thus reducing the chance of a type II error, a significant net loss is found.

The upper panel of Figure 21 shows data from an alternative scenario. Here, preliminary work revealed the high level of variance in the data and identified that a large proportion of it originated from channel units P3a, P3b, and BW2a (see Figure 17), all of which are large, deep pools in which electrofishing is very inefficient. The consultants supplemented the electrofishing data for these channel units with data from small mark recapture studies using minnow traps and short gill net sets. This reduced the data's variance appreciably and allowed confident identification of a net loss in rainbow trout biomass.

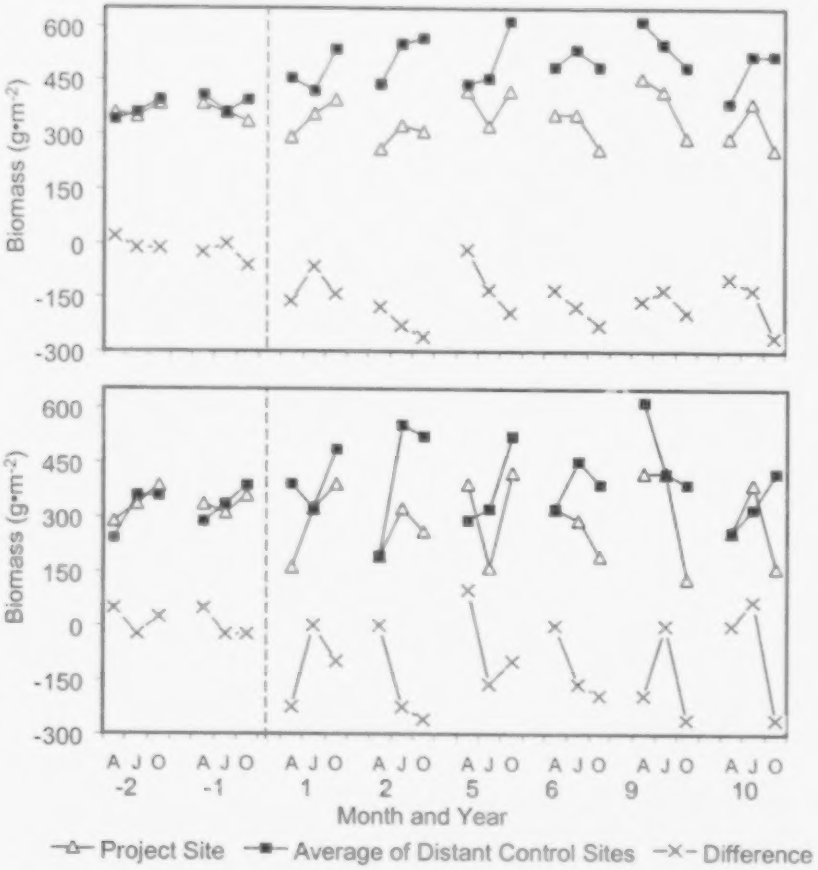
Using individual based measures may also allow detection of effects that would otherwise be masked by high variance. Figure 22 shows individual growth and relative weight of rainbow trout from the mark-recapture study. Fish in the project site showed a net loss in growth and condition throughout the post-project monitoring period similar in pattern to that found in the higher-variance biomass data.

7.2.7.3: Macroinvertebrates: Macroinvertebrate community structure changed in the immediate (1-2 year) aftermath of project construction showing net losses in both taxa diversity and the proportion of sensitive taxa (EPT index; Figure 23). By five years after construction, however, no net loss appears to have been achieved in these parameters. In contrast, macroinvertebrate abundance did not achieve NNL by the end of the monitoring period. As invertebrates are among the most rapid colonizers of new habitat, this suggests that water quality was unaffected by the project but that the site's carrying capacity for invertebrates was reduced. Reduced structural complexity, and lower standing crops of detritus and/or course woody debris have been shown to have this effect (Ward 1992).



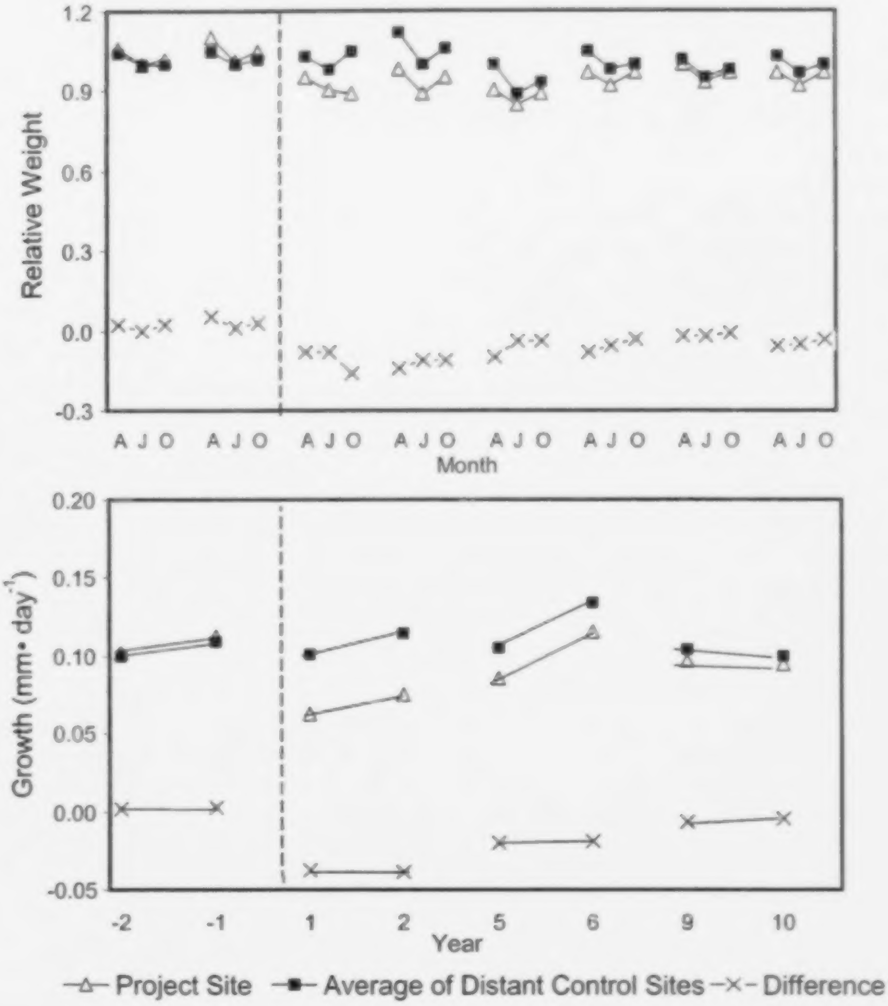
	Apparent Change			Local Movement Effect			Net Effect		
Year	1-2	5-6	9-10	1-2	5-6	9-10	1-2	5-6	9-10
D_A-D_B	-2.50	-1.38	0.23	-7.50	-4.60	-0.97	-5.00	-3.22	-1.20
SE	0.64	0.43	0.29	0.46	0.56	0.48	0.29	0.27	0.33
t	-3.92	-3.24	0.80	-16.40	-8.28	-2.01	-17.53	-11.97	-3.59
p	0.0029	0.0089	0.4423	<0.0001	<0.0001	0.0722	<0.0001	<0.0001	0.0018
Outcome	**NL**	**NL**	**NNL**	**NL**	**NL**	**NNL**	**NL**	**NL**	**NL**

Figure 20: Density of adult chiselmouth (*Acrocheilus alutaceus*) in the project site, distant control sites (top panel) and the local control site (bottom panel) over the full monitoring period (A=April, J=July, O=October). Vertical dashed lines indicate time of project construction. T-tests (2-tailed, df=10, t_{crit} = 2.228) compare the mean difference between the sites in each of three post-construction periods (years 1-2, 5-6 and 9-10) to the pre-construction period. P-values indicate significance. Of the significant results, negative t-values indicate a net loss. Density appears to increase in the project site relative to the distant control site, but the loss of density in the local control site more than accounts for this gain, revealing that a significant net loss of productive capacity in the reach actually occurred.



	Biomass: Electrofishing Only			Biomass: Multi-mode Sampling		
Year	**1-2**	**5-6**	**9-10**	**1-2**	**5-6**	**9-10**
D_A-D_B	-143	-94	-116	-157	-131	-147
SE	50.6	48.6	61.4	29.90	32.05	26.02
t	-2.83	-1.94	-1.89	-5.25	-4.09	-5.66
p	0.0179	0.0811	0.0881	0.0004	0.0022	0.0002
Outcome	**NL**	**NNL**	**NNL**	**NL**	**NL**	**NL**

Figure 21: Biomass of rainbow trout (*Oncorhynchus mykiss*) in the Big Trout River over the monitoring period (A=April, J=July, O=October). The lower panel shows data obtained by electrofishing only. In the top panel pot traps and short gill net sets were also used in difficult-to-sample, deep-water areas. Vertical dashed lines show time of project construction. T-tests (2-tailed, df=10, t_{crit} = 2.228) compare the mean difference between the sites in each of three post-construction periods (years 1-2, 5-6 and 9-10) and the pre-construction period. P-values indicate significance. Of the significant results, negative t-values indicate a net loss. This multi-mode sampling showed a persistent net-loss throughout the monitoring period that was detected only until year 2 by electrofishing-only due to high variation in the electrofishing data.



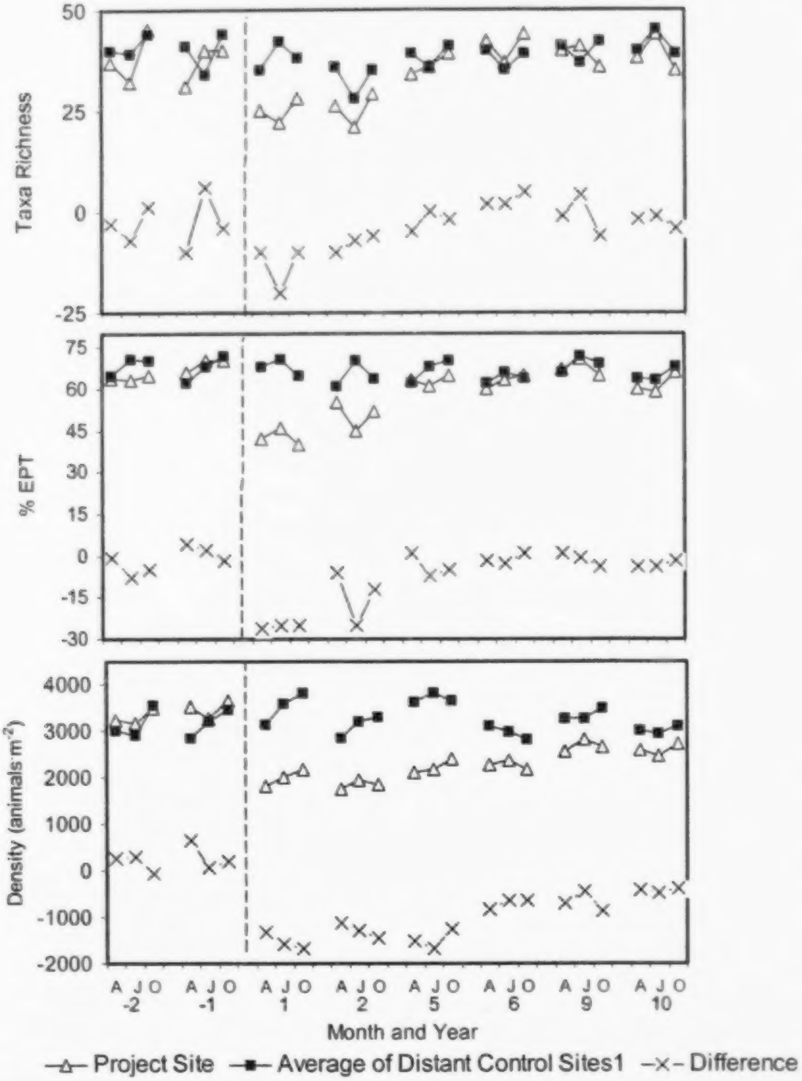
	Growth			Relative Weight		
Year	**1-2**	**5-6**	**9-10**	**1-2**	**5-6**	**9-10**
D_A-D_B	-0.135	-0.080	-0.053	-0.041	-0.022	-0.009
SE	0.015	0.013	0.011	0.001	0.001	0.001
t	-9.090	-6.096	-5.035	-57.983	-31.113	-7.603
p	<0.0001	0.0001	0.0005	0.0003	0.001	0.0169
Outcome	**NL**	**NL**	**NL**	**NL**	**NL**	**NL**

Figure 22: Growth and relative weight of rainbow trout (*Oncorhynchus mykiss*) at the project site and control sites during the monitoring period (A=April, J=July, O=October). Relative weight is a length corrected index of fish condition. Vertical dashed line indicates time of project construction. T-tests compare the mean difference between the sites in each of three post-construction periods (years 1-2, 5-6 and 9-10) to the pre-construction period. P-values indicate significance. Of the significant results, negative t-values indicate a net loss. Both parameters showed a significant net loss that persisted throughout the monitoring period.

7.2.7.4 Periphyton: Periphyton biomass (as ash-free dry mass; AFDM) increased dramatically in the years following construction, but returned to pre-project levels by the end of the monitoring period. Diatom taxa richness also showed a transient response, but in the opposing direction, declining in the years immediately following construction but achieving NNL by the end of the monitoring period (Figure 24). The loss of riparian shade in the early years of site development (see section 7.2.7.5) probably caused summer algal blooms – which, in turn, attracted chiselmouth from surrounding habitats (see section 7.2.7.2). The blooms lessened in intensity over time as the riparian plants matured, casting more shade.

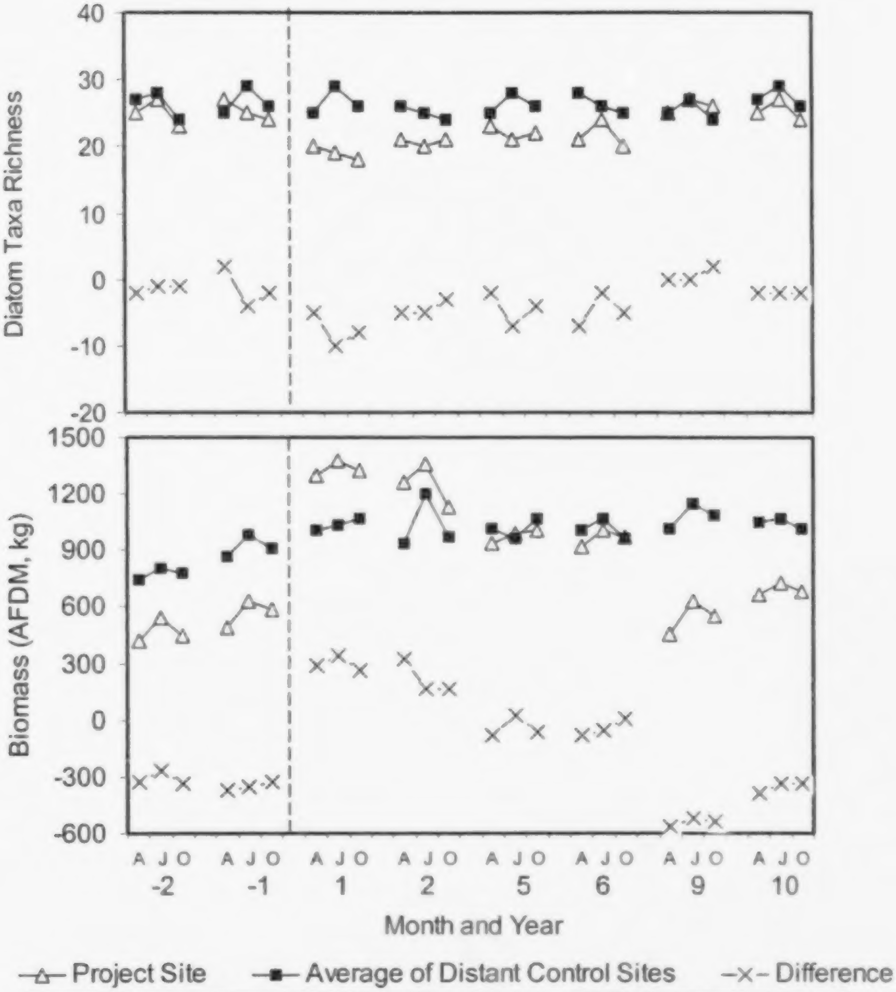
7.2.7.5 Riparian vegetation: Riparian stem density showed no-net-loss in the first two years following construction, but drought brought high plant mortality on the site in year three (Figure 25). Supplementary plantings in year four largely compensated for the losses but plant mortality continued to be a problem resulting in a NL even ten years after project construction. Percent cover over the channel (measured with a spherical densiometer) was extremely low in the newly constructed site, a large net loss relative to the HADD site. As riparian vegetation grew, the percent cover increased, but had still not achieved NNL ten years after project construction.

7.2.7.6 Water temperature: Water temperature increased through the compensation site (post-construction) more than through the HADD site (pre-construction, Figure 26). The difference decreased over time, presumably due to increased riparian shading, and after 10 years the difference was less than 1 ^{o}C. Although probably not biologically significant, even this small change was quite statistically significant due to low variance in the data. Mean daily temperature range followed a similar pattern, increasing greatly in the compensation site relative to the HADD site early in the monitoring period, with the difference declining in magnitude over time. No net change in temperature range was achieved in the last phase of monitoring.



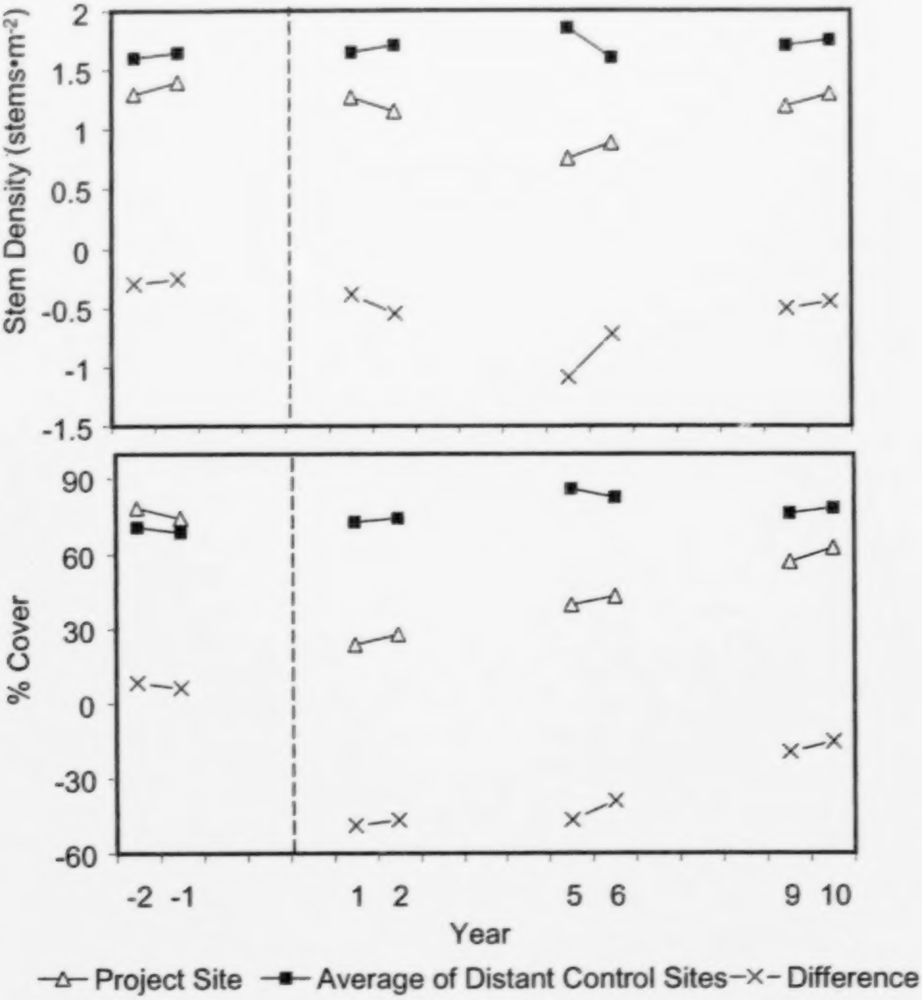
	Density			Percent EPT			Taxa Richness		
Year	**1-2**	**5-6**	**9-10**	**1-2**	**5-6**	**9-10**	**1-2**	**5-6**	**9-10**
D_A-D_B	-1631.8	-1325.8	-776.5	-18.17	-0.83	-0.67	-7.67	3.17	1.17
SE	131.42	210.14	128.31	3.95	2.23	1.99	3.09	2.73	2.71
t	-12.42	-6.31	-6.05	-4.60	-0.37	-0.34	-2.48	1.16	0.43
p	<0.0001	<0.0001	<0.0001	0.0005	0.719	0.741	0.033	0.273	0.676
Outcome	**NL**	**NL**	**NL**	**NL**	**NNL**	**NNL**	**NL**	**NNL**	**NNL**

Figure 23: Macroinvertebrate density, percent of individuals comprised of Ephemeroptera, Tricoptera and Plecoptera (%EPT), and taxa richness at the project site and control sites during the monitoring period (A=April, J=July, O=October). Vertical dashed line indicates time of project construction. T-tests (2-tailed, df=10, t_{crit} = 2.228) compare the mean difference between the two sites in each of three post-construction periods (years 1-2, 5-6 and 9-10) to the pre-construction period. P-values indicate significance. Of the significant results, negative t-values indicate a net loss. Although %EPT and taxa richness showed NNL by year 5, a significant NL of density persisted throughout the monitoring period.



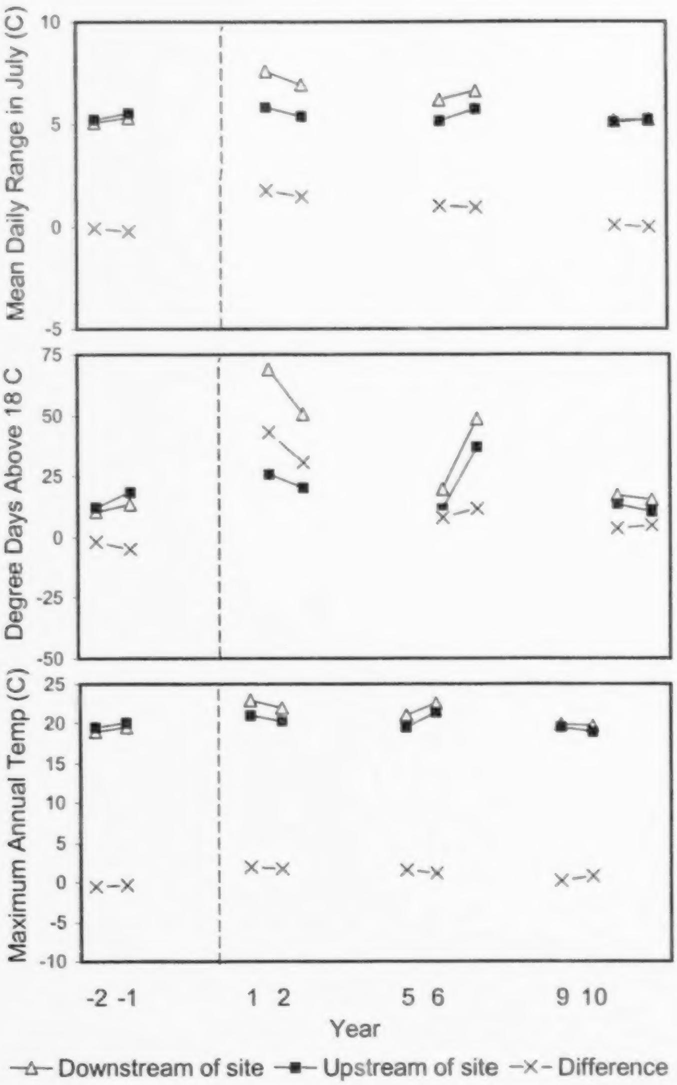
	Biomass			Diatom Taxa Richness		
Year	**1-2**	**5-6**	**9-10**	**1-2**	**5-6**	**9-10**
D_A-D_B	21.63	12.40	-0.10	-4.67	-3.17	0.67
SE	1.17	0.85	1.45	1.31	1.22	1.04
t	18.48	14.55	-0.07	-3.57	-2.59	0.64
p	<0.0001	<0.0001	0.9456	0.0051	0.027	0.5366
Outcome	**NG**	**NG**	**NNL**	**NL**	**NL**	**NNL**

Figure 24: Periphyton biomass (ash free dry mass; AFDM) and diatom taxa richness at the project site and control sites over the monitoring period (A=April, J=July, O=October). Vertical dashed line indicates time of project construction. T-tests (2-tailed, df=10, t_{crit} = 2.228) compare the mean difference between the two sites in each of three post-construction periods (years 1-2, 5-6 and 9-10) to the pre-construction period. P-values indicate significance. Of the significant results, negative t-values indicate a net loss. Both variables showed NNL by year 9 following initial significant net increases (net gain) in biomass and decreases in diatom taxa richness.



	Riparian Stem Density			Percent Canopy Closure		
Year	**1-2**	**5-6**	**9-10**	**1-2**	**5-6**	**9-10**
D_A-D_B	-0.190	-0.630	-0.200	-54.90	-50.00	-24.51
SE	0.089	0.110	0.026	1.39	4.04	2.19
t	-2.144	-5.743	-7.805	-39.60	-12.37	-11.18
p	0.1652	0.0145	0.0016	0.0006	0.0065	0.0079
Outcome	**NNL**	**NL**	**NL**	**NL**	**NL**	**NL**

Figure 25: Measures of riparian vegetation development over time at the project site and distant control sites. Vertical dashed line indicates time of project construction. T-tests (2-tailed, df=2, t_{crit} = 4.303) compare the mean difference between the sites in each of three post-construction periods (years 1-2, 5-6 and 9-10) to the pre-construction period. P-values indicate significance. Of the significant results, negative t-values indicate a net loss. Riparian stem density showed NNL after the first monitoring period but drought conditions caused a net loss in later years. Canopy closure showed significant net losses throughout the post-construction monitoring period.



	Maximum Annual Temperature (C)			**Degree Days Above 18 C**			**Mean Daily Temperature Range in July (C)**		
Year	**1-2**	**5-6**	**9-10**	**1-2**	**5-6**	**9-10**	**1-2**	**5-6**	**9-10**
D_A-D_B	2.35	1.75	0.95	40.32	13.17	7.77	1.80	1.15	0.18
SE	0.11	0.13	0.09	6.55	2.39	1.63	0.16	0.07	0.06
t	21.02	13.91	10.56	6.16	5.50	4.78	11.38	16.26	3.13
p	.0023	.0051	.0088	.0254	.0315	.0411	.0076	.0038	.0887

Figure 26: Changes in temperature variables in riffles immediately upstream and downstream of the project site over time. Vertical dashed line indicates time of project construction. T-tests (2-tailed, df=2, t_{crit} = 4.303) compare the mean difference between the two sites in each of three post-construction periods (years 1-2, 5-6 and 9-10) to the pre-construction period. All differences showed statistically significant increases following project construction and remained elevated throughout the post-project monitoring period, but the magnitude of difference by year 9 was unlikely to be biologically significant.

7.2.8 Conclusions

On balance, DFO biologists concluded that no-net-loss of habitat productive capacity had not been fully achieved ten years after construction of the Big Trout River compensation project. A number of parameters, including total fish biomass, number of kokanee spawners, periphyton biomass, and diversity of diatoms and macroinvertebrates had achieved no-net-loss. However, several other important parameters including biomass, growth and condition of the rainbow trout population, macroinvertebrate abundance, and riparian vegetation density all showed substantial net losses even after factoring the compensation ratio into the NNL determination for density and biomass measurements. This case study underlines the importance of using an array of indicators to assess no net loss. Measuring only a few would likely have given a skewed impression of project success and would have provided less mechanistic information.

The importance of a local control site in assessing mobile fish populations was emphasized by the chiselmouth data, which showed that an apparent net gain in production at the compensation site was, in fact, accounted for by temporary immigration from neighbouring habitats. The utility of several approaches to dealing with high-variance data sets was shown. The ability of the BACIP design to control for interannual variation that affects both control and project sites was evident in the juvenile chinook salmon density data set. In the rainbow trout data set net loss in biomass was detectable by both increasing sampling effort and adopting more efficient methods or by relaxing alpha (the acceptable probability of detecting a false effect). Reduced variance in individually based parameters (growth and condition) also permitted detection of net loss in productive capacity for trout.

As a result of the assessment, NFI was required to increase in-stream complexing of the new channel in the hopes of increasing macroinvertebrate production and the quality of deep pool habitat for adult rainbow trout. No net loss was achieved within two years of this supplementary work.

7.3 CASE STUDY 3: LOST CREEK PIPELINE CROSSING

7.3.1 Site and Project History

DFO has issued a Section 35(2) authorization for a pipeline crossing of Lost Creek in northern Ontario. Permanent rip-rapping of the channel bottom around the crossing will be necessary to protect it from erosion and will affect 150 m^2 of in-channel pool habitat. There will be no loss of riparian habitat. The species of primary management concern at the project site are brook trout (*Salvelinus fontinalis*) and a stocked population of rainbow trout (*Oncorhynchus mykiss*). A community of cyprinids and two species of catostomids are also present. The populations of all species in Lost Creek are believed to be robust and there are no obviously degraded areas that would benefit from a compensation project.

In contrast, managers are concerned about the status of small populations of largemouth bass (*Micropterus salmoides*) and yellow perch (*Perca flavescens*) that inhabit a short marshy reach in a neighbouring stream (Chipmunk Creek, Figure 27) where angling pressure is increasing. As a result, DFO and the proponents of the pipeline crossing agreed that the proponents will construct off-channel pool habitat totaling at least 405 m^2 (compensation ratio of 2.7:1) to compensate for the HADD to in-channel habitat that results from the project.

7.3.2 Project Objective

To achieve NNL by increasing habitat productive capacity for largemouth bass and yellow perch on Chipmunk Creek to compensate for a loss of habitat productive capacity for salmonids in Lost Creek due to the HADD resulting from the pipeline crossing.

7.3.3 Project Design

The approved design consists of a 405 m^2 off-channel pool complexed with large woody debris and planted with native wetland species. It is intended to provide habitat for all life history stages of largemouth bass and yellow perch to increase their population size and stability.

7.3.4 Monitoring and Assessment Goals

Assess the net change in productive capacity of the compensation site (off-channel pool habitat) relative to the HADD site (rip-rapped mainstem in-channel pool habitat) using a range of biotic and abiotic indicator variables.

7.3.5 Monitoring Program

7.3.5.1 Experimental Design: A before-after-control-impact-paired (BACIP) experimental design with spatially nested control sites is applied to the biological variables (Table 11). Pre-project monitoring is limited to a single year. Post project monitoring is done in years 1, 2, 5, 6, 9, and 10. This allows net changes in variables to be statistically assessed immediately after (years 1 and 2), in the short term (years 5 and 6) and in the medium term (years 9 and 10) following project construction. The site is sampled three times annually, in April, July and October in both the pre and post-monitoring periods. See section 5.4 for details on experimental design.

An as-built survey is conducted in the first year following construction and confirms that the project meets the approved area requirements and design specifications. The consultants assess physical habitat at the HADD and the compensation site throughout the monitoring period and find that its area, structural integrity, and configuration remain acceptable. Here we focus our attention on the assessment of its productive capacity.

Two control sites for evaluating loss of habitat productive capacity at the HADD site are established on Lost Creek (Figure 27). Each is a 75 m section of stream; one is approximately 3 km upstream of the pipeline crossing site and the other approximately 7 km upstream of it. These locations were chosen for ease of access and to minimize the likelihood of the project influencing them. Both are very similar to the pipeline-crossing site with respect to channel size, gradient, substrate size, riparian zone condition and temperature.

Two additional sampling sites are established on Chipmunk Creek as controls for the compensation site. One, a local control, is used to assess the effects of fish movement (see section 5.4.1). It is located 500 m upstream of the compensation site. The other, a distant control site is used to track natural inter-annual variation in all parameters and is located several kilometers away on an unnamed tributary to Chipmunk Creek. Both of these sites are relatively deep, marshy reaches with abundant large woody debris and similar thermal regimes to the compensation site.

7.3.6 Monitoring Methods

7.3.6.1 Fish: As Lost Creek is wadeable, fish sampling at the HADD site and its control sites are sampled using a three-pass removal protocol with a backpack electroshocker. The channel units are isolated with stop nets and sampled separately. At the crossing this consists of the rip-rapped pool (length 20 m). At each control site, two 20 m sections of pool are used.

Habitat at the compensation site and its control sites are too deep for electrofishing, and are sampled using baited minnow traps and gill nets (15 minute daytime sets to reduce mortality). Here sampling occurs on three consecutive days and all captured fish are marked by fin-clipping. Abundance is estimated using a Petersen mark-recapture study design (Krebs 1989). As the creek is small, it is blocked by stop nets for the sampling period to ensure that immigration and emigration is zero, an important assumption of the Petersen method (Krebs 1989).

At all sites, density is calculated for each species and life stage by dividing abundance by sampled area (number/m^2). Biomass is calculated by dividing mean individual weight by the total area of each site. To take into account the differences in habitat area between the HADD area and compensation area, each parameter is expanded by the compensation ratio. Adult fish are weighed (nearest 0.1 g) and measured (fork length, nearest mm). Juveniles are processed similarly, but subsampled (n=30 per species) when large numbers are captured. Rainbow and brook trout are marked with pit tags to allow monitoring of growth between sampling periods. Relative weight, a length corrected measure of condition (Anderson and Neumann 1996), is calculated for all species and life stages.

7.3.6.2 Macroinvertebrates: At the HADD site and its controls as well as the compensation site and its controls, four replicate samples site were collected in shallow areas (<50 cm depth) using a Hess sampler and preserved in 5% formalin. They were sorted and invertebrates were identified to genus or species in the laboratory. Total taxa richness, total density, and the EPT index (percentage of organisms in the mayfly, (Ephemeroptera), stonefly (Plecoptera) and caddisfly (Trichoptera) families) were calculated. Samples were archived in case more detailed future analyses is required.

7.3.6.3 Periphyton: In the HADD site, compensation site and their controls, a rapid coverage and thickness survey was conducted as described in section 7.1.6.4. In addition, biomass was measured (as ash free dry mass, AFDM) and the total number of macroalgae and diatom species, and the Shannon diversity index for diatoms were calculated.

Biomass samples were collected using four replicate periphytometers at each site. Each unit contained clean glass microslides and was placed at a standard location in late June. Following a six-week incubation period, accumulated periphyton was removed from all slides. A subsample from a single slide in each periphytometer was used to identify macroalgae and diatoms to species. Samples from the remaining slides were pooled and used to measure biomass (as AFDM).

7.3.6.4 Macrophytes: Area and percent coverage of macrophytes in the compensation site and its control sites were measured using a surveyor's transit and standard methods. Stem density within a random sample of beds planted in the compensation site was compared to those in natural beds of both control sites (four beds per site, 10 subsamples per bed).

Table 11: Biotic and abiotic variables measured in the Lost Creek monitoring program.

	Variable	Sampling Methods
Fish	- Biomass and Density o Total o By species and life stage	HADD and HADD Controls - Backpack Electroshocker (three pass removal in each channel unit) Compensation and Compensation Control - Minnow Trap (20 sets per site) - Gillnet (eight 15 minute sets per site)
	- Growth Rates - Condition	- Pit tag adult rainbow trout, brook trout at HADD and control sites
Macroinvertebrates	- Density - EPT index - Taxa Richness	- Hess sampler in shallow water of pool (four replicates per site)
Periphyton	- Rapid coverage and thickness survey	- Viewing bucket at points on transects in shallow area of pool.
	- Biomass - Total number genera - Shannon diversity index for diatoms	- Six-week growth on periphytometers containing glass substrate (four per site).
Macrophytes	- Area - Percent site coverage	- Areas measured during topographic survey
	- Stem density in beds	- Stem counts within quadrats in four randomly selected beds

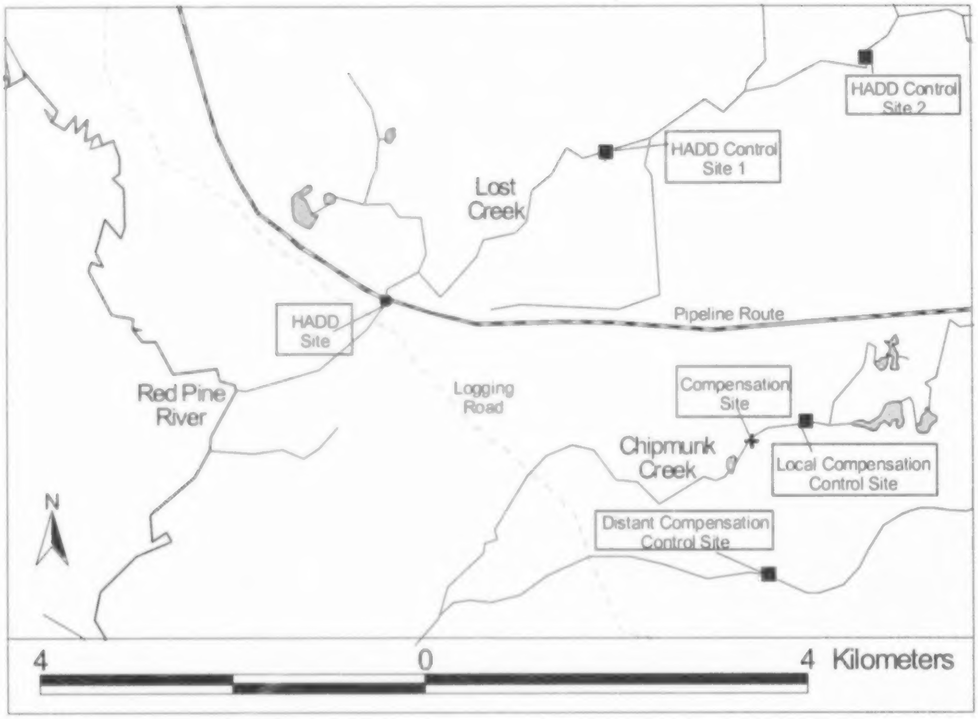

HADD Control Site 2
HADD Control Site 1
Lost Creek
Pipeline Route
HADD Site
Logging Road
Red Pine River
Compensation Site
Chipmunk Creek
Local Compensation Control Site
Distant Compensation Control Site
N
4
0
4 Kilometers

Figure 27: Locations of HADD, compensation and control sites for the Lost Creek monitoring study. The HADD control sites are located 3 and 7 km upstream of the HADD site. The compensation site is located on Chipmunk Creek approximately 500 m downstream of a marshy reach that serves as its local control site. A distant control site for the compensation site is located on an unnamed tributary to Chipmunk Creek.

7.3.7 Results and Discussion

7.3.7.1 Area Verification and NNL Calculation: A survey of the HADD site revealed that the area of in-channel habitat destroyed closely matched the 150 m^2 listed in the authorization. In this case, the area actually constructed in off-channel compensation also closely matched the 450 m^2 required, producing an actual compensation ratio of 2.7:1.

In net change calculations, outcomes were obtained by multiplying area-specific parameters (e.g. g/m^2) by the actual compensation ratio to take into account the difference in impacted versus compensated area. Parameters not expressed in area-specific terms are not expanded, but are important to detail the range of potential habitat changes and are used as weight of evidence to support NNL determinations (see section 5.4.9).

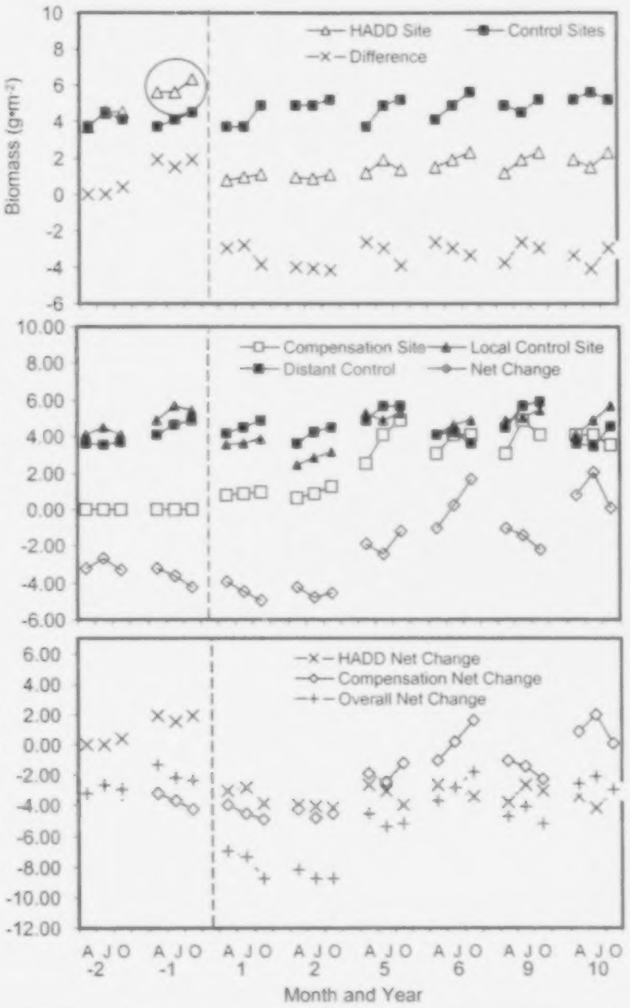
7.3.7.2 Fish: When a single year of baseline data was used, neither total fish biomass (not shown) nor sport-fish biomass (rainbow trout, brook trout, largemouth bass and yellow perch) achieved no net loss at any point during the ten-year post-project monitoring period. However, had a second year of baseline data been collected NNL would have been easily achieved by years 5 and 6 (Figure 28). The difference is due to high fish biomass estimates at the HADD site in the year before construction. These resulted in an inflated estimate of the HADD's impact. Had a second year of baseline monitoring been included, the average of the two would have been used in the calculations and the impact estimated as much lower. Growth rates of both species of salmonid declined at the HADD site relative to its control sites (not shown).

The use of different capture methods in the compensation site (traps and gillnets vs. electrofishing) is a concern. All methods are biased with respect to factors like fish size, behaviour, and possibly sex and mixing. When the same methods are used, bias is likely to be similar at all sites and NNL calculations will be affected minimally. Mixing methods, as was necessary here, will produce unequal biases among sites, which may alter NNL assessment. When possible the methods should be calibrated (e.g. use both methods in the same habitat to develop a correction factor). This situation is much less likely to arise in like compensation projects where the same methods are used throughout the study.

7.3.7.3 Macroinvertebrates: Macroinvertebrate biomass achieved no-net-loss within five years (Figure 29). It remained at a relatively constant low level in the HADD site following construction, but increased notably over time in the compensation site. Taxa richness and percent EPT taxa also showed no detectable difference within five years (not shown).

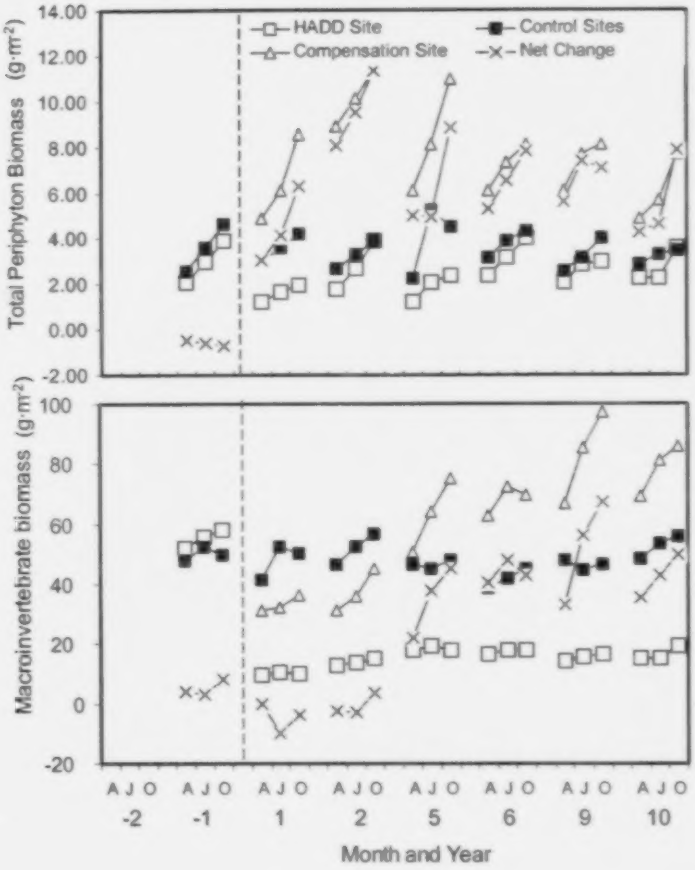
7.3.7.4 Periphyton: Periphyton biomass showed a net gain within one year, and this increased over the course of the monitoring period (Figure 29). Heavy growth in the relatively large compensation site was responsible, perhaps due to warmer water temperatures there.

7.3.7.5 Macrophytes: Macrophyte coverage and stem density were as required in the authorization within five years and coverage significantly exceeded requirements by year nine (not shown).



	One Year Baseline			Two Year Baseline		
Year	**1-2**	**5-6**	**9-10**	**1-2**	**5-6**	**9-10**
D_A-D_B	-6.18	-1.92	-1.64	-5.69	-1.43	-1.15
SE	0.45	0.66	0.60	0.43	0.64	0.58
t	-13.71	-2.92	-2.74	-13.31	-2.22	-1.97
p	<0.0001	0.0223	0.0289	<0.0001	0.1507	0.1771
Outcome	**NL**	**NL**	**NL**	**NL**	**NNL**	**NNL**

Figure 28: Changes in combined standing crop of managed species during the monitoring period (A=April, J=July, O=October). The HADD and its control sites (top) contain rainbow trout and brook trout. The compensation site and its control sites (middle) contain largemouth bass and yellow perch. Local and distant control sites were included for the compensation site. Vertical dashed line indicates time of project construction. T-tests compare the mean difference between pre-project and each of three post project monitoring periods (2-tailed, df=7, t_{crit} = 2.365 1 yr of pre-project monitoring, df=10, t_{crit}=2.228 for 2 yrs of pre-project monitoring). P-values indicate significance. Of the significant results, negative t-values indicate a net loss. Only one year of pre-project data (year '-1') was actually collected. As it was very productive that year (-1) in the HADD site (circled points), project effects were overestimated and NNL was apparently not achieved. Inclusion of a second year of pre-project data (year '-2') showed that NNL was actually achieved by year 5 (bottom and tables).



	Periphyton Biomass			Macroinvertebrate Biomass		
Year	**1-2**	**5-6**	**9-10**	**1-2**	**5-6**	**9-10**
D_A-D_B	7.65	7.01	6.73	-7.9	34.2	42.2
SE	1.30	0.67	0.62	2.4	4.0	5.6
t	5.88	10.54	10.81	-3.27	8.44	7.59
p	0.0003	<0.0001	<0.0001	0.0137	<0.0001	<0.0001
Outcome	**NG**	**NG**	**NG**	**NL**	**NG**	**NG**

Figure 29: Changes in biomass of the standing crop of periphyton and macroinvertebrates at the HADD, control and compensation sites during the monitoring period (A=April, J=July, O=October). Dashed vertical lines indicate time of project construction. T-tests compare the mean difference between the two sites in each of three post-construction periods (years 1-2, 5-6 and 9-10) to the pre-construction period (2-tailed, df=7, t_{crit} = 2.365). P-values indicate significance. Of the significant results, negative t-values indicate a net loss. Periphyton biomass showed at net gain throughout the post-construction monitoring period. Macroinvertebrate biomass declined significantly immediately following construction but showed a net gain by year 5.

7.3.8 Conclusions

Due to the short pre-project monitoring period, a net-loss of habitat productive capacity was found where none really occurred. Consequently the proponents were required by DFO to construct more off-channel habitat and to monitor it for an additional five years, at considerable expense. Had a second year of pre-project monitoring data been collected, some of the natural year-to-year variance would have been captured and the year prior to construction would have been recognized as exceptionally productive at the HADD site. Averaging with the year before, which was much less productive, would have reduced its influence on the analysis. The example highlights the importance of multi-year pre-project monitoring. The assumption is when collecting a single year of baseline data that it represents average conditions. Should it in fact be an exceptionally productive or unproductive year, errors will likely be made in assessing no-net-loss. The result will either be increased work and expense for proponents, as in this example, or undetected habitat degradation.

The case study also illustrates the subjectivity of assessing NNL in unlike compensation projects. The two habitats are inhabited by different species. The species of management concern at the HADD site were rainbow trout and brook trout, and their populations suffered a clear net loss of biomass due to the project. Both salmonid species are abundant in the system and managers decided to use the compensation project to bolster largemouth bass and yellow perch populations in the watershed, albeit on a different tributary. The finding of NNL in this case rests on the assumption that all four species are of equivalent and interchangeable value.

7.4 CASE STUDY 4: GILLIS COVE MARINA DEVELOPMENT

7.4.1 Site and Project History

Gillis Cove is part of Nova Scotia's Auk River estuary (Figure 30), an important rearing area for over 20 species of fish, including Atlantic salmon (*Salmo salar*), winter flounder (*Pleuronectes americanus*), and Atlantic cod (*Gadus morhua*). Although historically large, the Auk River salmon run has dwindled in recent decades but there are hopes that that a habitat restoration program in the upstream reaches will induce some recovery. The estuary habitat is not thought to currently limit the population but there are concerns among managers and local stewards that it may, should the population continue to recover. The southwestern portion of the cove was also an important source of shellfish for local First Nations people prior the construction of log storage facilities there in the 1930s. The facilities were abandoned in the late 1970s, but drift logs and debris accumulations continue to impact approximately 30 hectares of the estuary as it receives little natural flushing.

In recent years the nearby town of Ripples has expanded and its suburbs now extend to within a few kilometers of the cove. This has caused a large increase in recreational boat use based out of the cove, putting significant pressure on the small government wharf there. Construction of a large commercial marina by a development consortium was recently approved for a small embayment on the cove's eastern shore. DFO has issued an authorization for a HADD in connection with the development. Impacts from infilling, buildings, wharves, and heavy boat traffic are estimated to affect a total of 6,000 m^2 of sub-tidal fish habitat, of which a small amount (60 m^2) is high value eelgrass and the remainder relatively lower value habitat. As a condition of the authorization DFO has stipulated that the consortium must restore a portion of the estuary damaged by historical log storage. A compensation ratio of 4:1 has been negotiated due to uncertainties around the extent and timeframe of increases in productive capacity that will occur on the compensation site.

7.4.2 Project Objective

Achieve no net loss in the productive capacity of Gillis Cove for the combined fish community, Atlantic salmon and shellfish.

7.4.3 Project Design

The approved compensation project consists of physical removal of bark and debris and restoration of 24,000 m^2 of the estuary's shallow intertidal area. As eelgrass has been identified as a potentially limiting factor, a portion of the cleared area (240 m^2) is to be seeded with eelgrass shoots transplanted from the impacted area as well as harvested from extensive beds a few kilometers up the coast. Overall, the site is intended to provide habitat for shellfish, juvenile Atlantic salmon, and other estuary dependant species including Atlantic cod and winter flounder.

7.4.4 Monitoring and Assessment Goals

- Assess the net change in productive capacity of the compensation site relative to the HADD site using a range of biotic and abiotic variables (fish biomass, eelgrass stem density and area of coverage, bivalve biomass and growth rates, benthic invertebrate species richness, as well as water temperature, dissolved oxygen, salinity and turbidity).

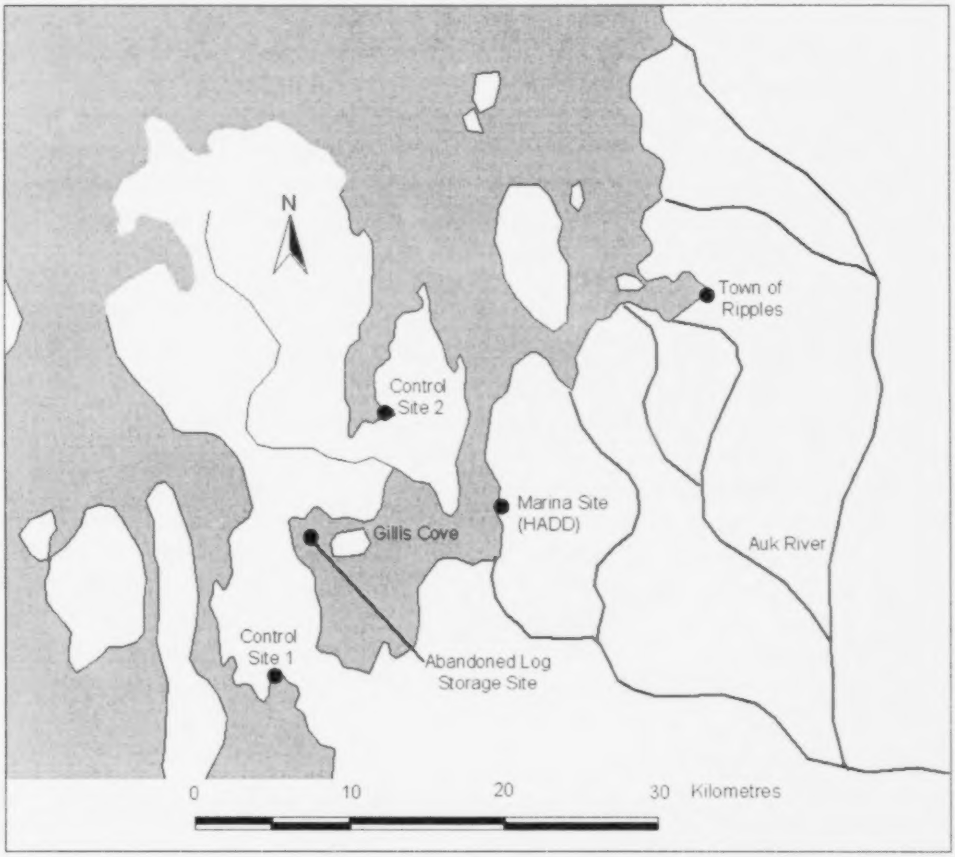


Figure 30: Locations of the Marina (HADD) site, the abandoned log storage (compensation) site and the two control sites for the Gillis Cove monitoring study.

7.4.5 Monitoring Program

A before-after-control-impact-paired (BACIP) experimental design with two distant control sites is used. The distant control sites are chosen to be physically similar to the HADD site, but located at least 5 km away by water (Figure 30). A local control site is not included in the design because the open nature of marine/estuarine habitats precludes meaningful estimates of immigration/emigration effects. Two years of pre-project monitoring and six years of post project monitoring are done. Post-project monitoring is spread over ten years (years 1, 2, 5, 6, 9 and 10). Sampling is conducted three times annually (April, July and October). The consortium's consultants conduct an as-built

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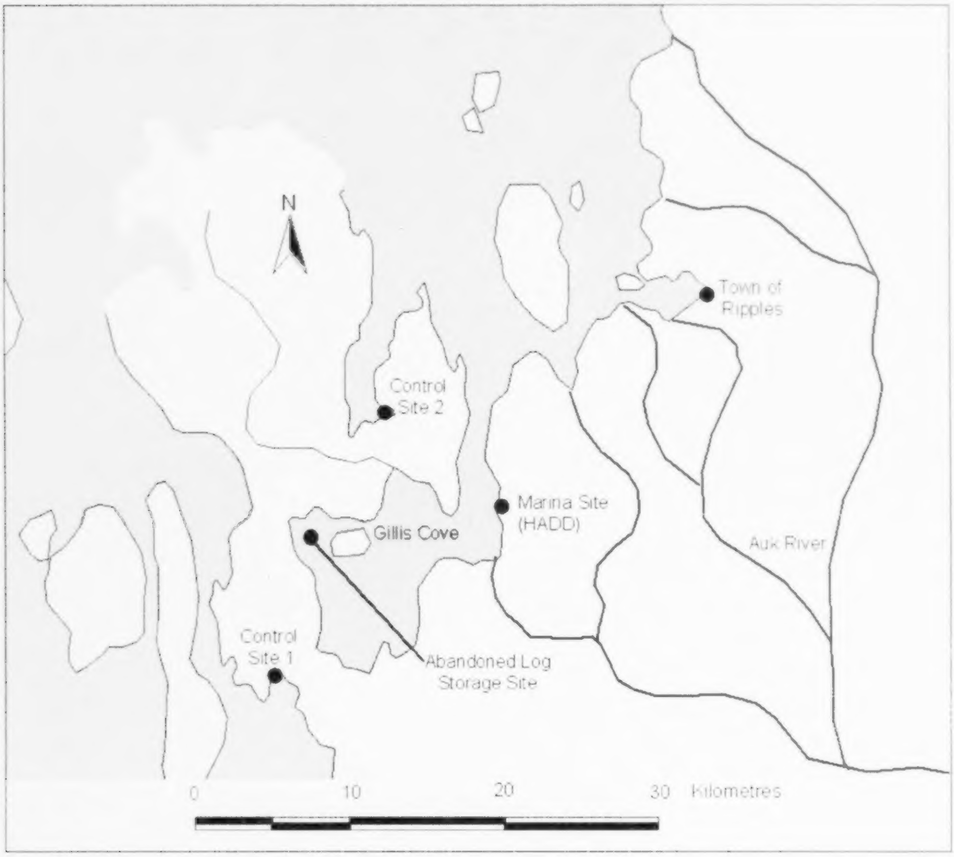

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7.4.6 Monitoring Methods

7.4.6.1 Fish: Quantitative estimates of biomass for marine fish are very difficult to generate using mark-recapture methods because of the large numbers of individuals and the very open nature of the habitat. Generally, active methods that sample known areas are used (e.g. seines or trawls; Robinson et al. 1996). These methods, however, are likely to cause unacceptable damage to eelgrass beds, particularly newly seeded ones like the compensatory eelgrass. Consequently a combination of passive capture methods (gill nets and baited minnow traps) and quantified observational methods (SCUBA transects) are used.

Gill nets are set in four groups of two. They are 30 m long, multi-paneled with mesh sizes ranging from 1 to 10 cm (stretched), and are set in an L-shaped configuration with one parallel to shore and one perpendicular to it (Robinson et al. 1996). Each set commences at a daytime low slack tide and lasts for 4 hours. Thirty minnow traps are also set for 24 hours. Two sets of permanent transects are established at each site. Each set consists of two transects (100 m long and 1.5 m wide) in a T-shaped configuration. It is sampled by two divers starting 10 min apart. The first diver swims well above the substrate, carrying a video camera and counts visible fish within the transect band. The second diver probes the substrate to flush demersal fish. All are identified to species and are categorized into length categories (< 5 cm, 5 to 15 cm, 15 to 30 cm and >30 cm).

Biomass is estimated by multiplying density estimates (fish/m^2) from the SCUBA surveys for each species-length class by the mean weight for that class obtained from fish captured in gill nets and traps. Catch-per-unit-effort data from the nets and traps are also calculated as an independent index of density. Relative weight, an index of fish condition, is calculated for all species and life stages of captured fish (Anderson and Neumann 1996).

7.4.6.2 Eelgrass (other restored habitat features not shown): Stem density and area of coverage is measured at each site in July of each year. Density is measured by divers who count live stems in 0.1 m^2 quadrats. Sampling is stratified by depth. Ten quadrats in each of three depth zones are sampled at the HADD and control sites and the results averaged for the site. Area measurements of eelgrass coverage are made from aerial photographs taken at low tide.

7.4.6.3 Bivalves: Bivalves are collected using a 0.1 m^2 van Veen grab which penetrates to a depth of 25 cm in soft substrates. Samples are taken every

10 m along a 100 m transect parallel to shore at a depth of 1 m below zero chart datum. Density of species is reported as number per m^2. Shell lengths of abundant species are measured and size distributions compared using a chi-square analysis. Growth rates of standard sized (15 mm) Northern Quahog (*Mercenaria mercenaria*) obtained from a local nursery and planted in subtidal pens are measured each October.

7.4.6.4 Benthic Invertebrates: Invertebrates are subsampled from every second van Veen grab sample (see bivalves above) and preserved in formalin. Individuals are identified to genus or species in the laboratory and total taxa richness is recorded. Density (per m^2) and total site biomass for each taxa is calculated.

7.4.6.5 Physical and Chemical Parameters: Water temperature is recorded using a data logger situated at the approximate center of each site. Dissolved oxygen and salinity is measured using a hand held meter and turbidity is measured using a secchi disk at the same location on all sampling days.

7.4.7 Results and Discussion

7.4.7.1 Area Verification and NNL Calculation: A survey of the HADD site revealed that the area of habitat destroyed closely matched the 6,000 m^2 listed in the authorization. The compensation area actually constructed also closely matched the 24,000 m^2 required achieving an actual compensation ratio of 4:1.

In net change calculations, outcomes were obtained by multiplying area-specific parameters (e.g. g/m^2) by the actual compensation ratio to take into account the difference in impacted versus compensated area. Parameters not expressed in area-specific terms are not expanded, but are important to detail the range of potential habitat changes and are used as weight of evidence to support NNL determinations (see section 5.4.9).

7.4.7.2 Fish: Unfortunately, too few Atlantic salmon juveniles were captured during the study to assess trends. Total fish biomass was significantly reduced for at least six years following construction, but no-net-loss was achieved by year ten (Figure 31). Catch-per-unit-effort data (not shown) followed a similar trend. Seasonally, biomass increased sharply in the fall due to a large immigration of juvenile winter flounder.

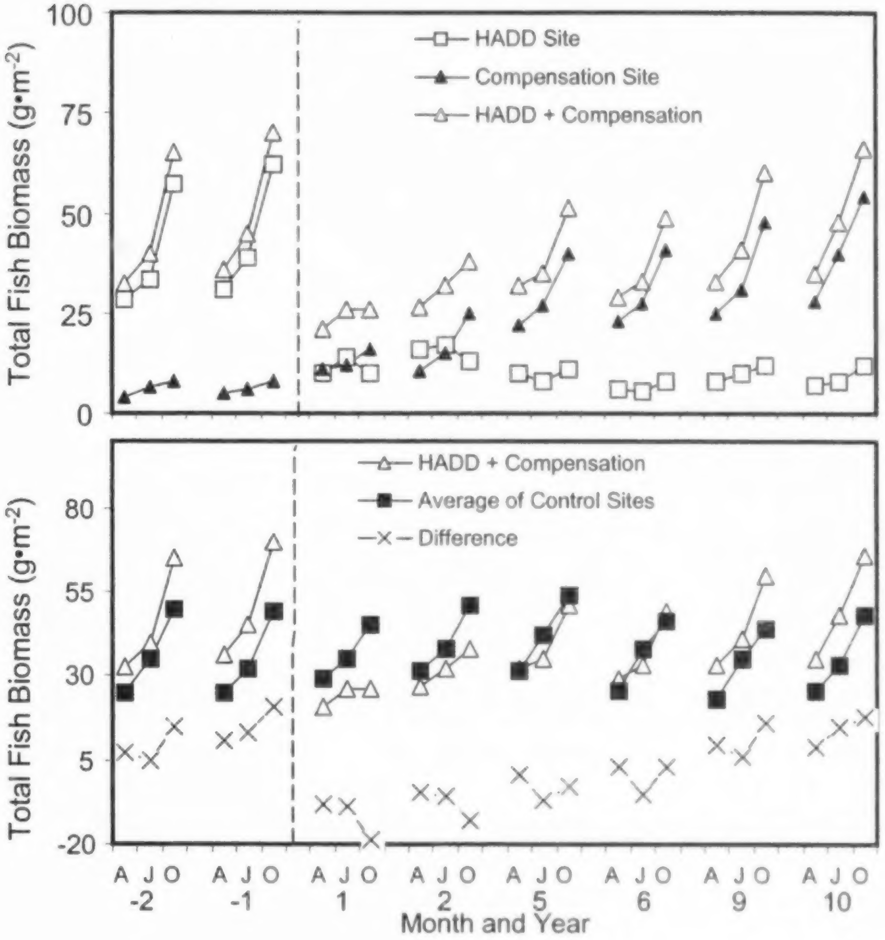
7.4.7.3 Eelgrass (measures of other habitat restoration not shown): Total eelgrass area was greatly increased following construction due to the high compensation ratio, but declined steadily for the first six years following construction (Figure 32) due to physical disturbance and high turbidity caused by boat traffic (see section 7.4.7.6). In the spring of year 7, the lost area was reseeded and the site closed to powerboats. In response, losses halted and total area increased slightly by year ten. Stem density in the compensation project was also reduced relative to the HADD site following construction and failed to increase during the first six years, but achieved no-net-loss by year ten, probably in response to the power boat closure.

7.4.7.4 Shellfish: Bivalve biomass per unit area was reduced approximately seven fold by the HADD and was near zero in the compensation site prior to restoration (Figure 33). It increased steadily in the compensation site in the years following construction, but failed to reach the pre-construction levels of the HADD site. The high compensation ratio, however, ensured that no-net-loss was achieved by year 6 and that a significant net gain occurred by the end of the monitoring period.

Growth rates of northern Quahog were dramatically reduced for the first six years following project completion, perhaps due to depressed primary productivity caused by high turbidity (Figure 34). No-net-loss was quickly achieved following the power boat ban.

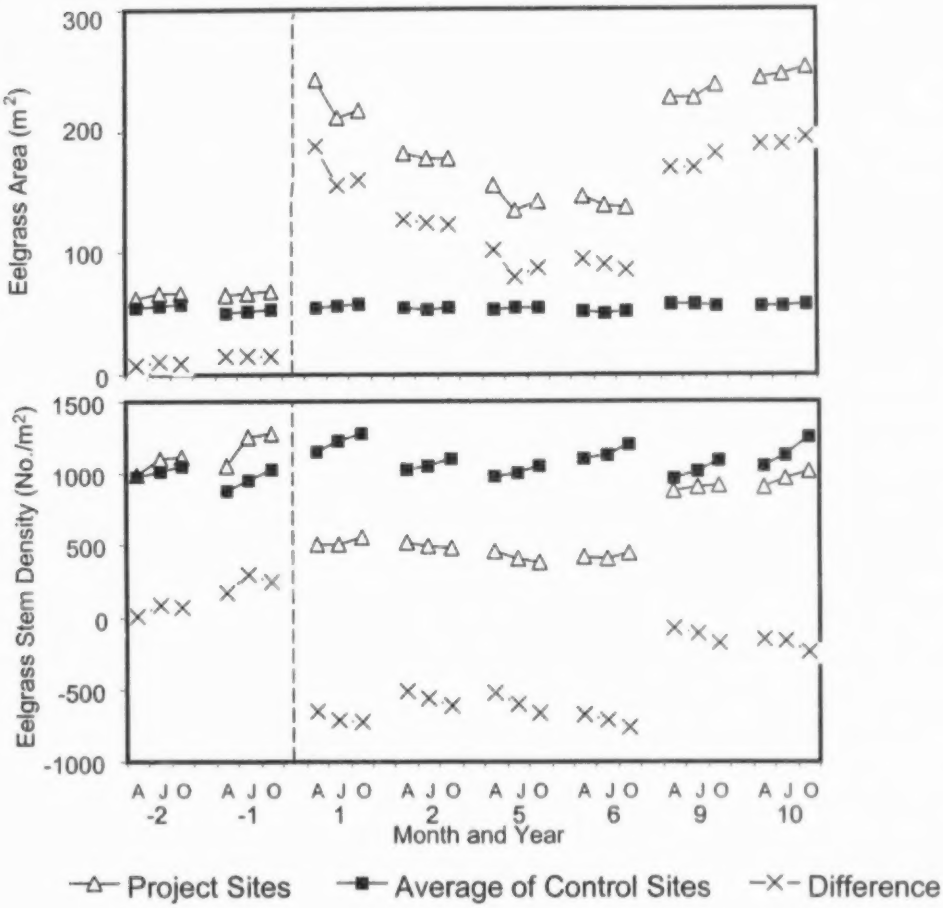
7.4.7.5 Macroinvertebrate Species Richness: Macroinvertebrate diversity was 73% lower in the compensation site immediately after construction than in the HADD site prior to it, but achieved no-net-loss by year 10 (Figure 34). Total density and biomass, recovered within six years (not shown).

7.4.7.6 Physical and Chemical Parameters (not shown): Dissolved oxygen levels increased markedly in the compensation site following restoration, presumably as a result of decreased biochemical oxygen demand from the bark and wood waste that had previously blanketed the site. Turbidity increased significantly until year six when the power boat moratorium was put in effect. Prior to the project the wood waste prevented sediment suspension from the boats. Temperature and salinity cycled seasonally, but did not change significantly among years or sites.



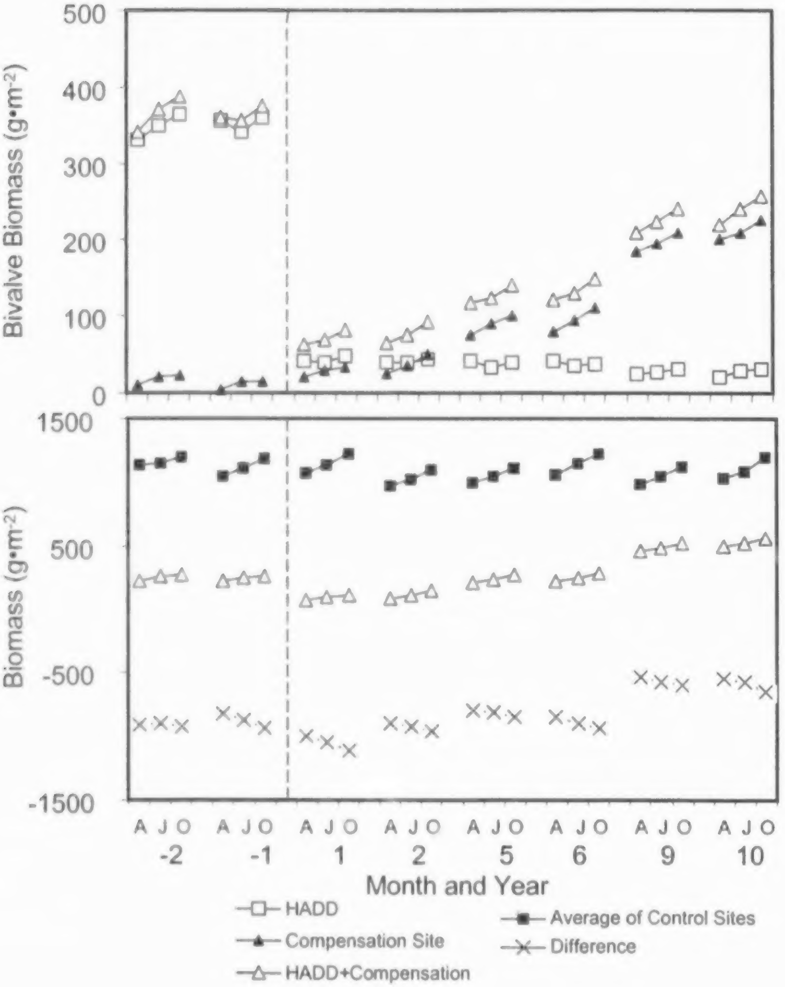
	Total Fish Biomass		
Year	**1-2**	**5-6**	**9-10**
D_A-D_B	-21.95	-13.33	-0.30
SE	3.18	2.93	3.03
t	-6.90	-4.56	-0.10
p	<0.0001	0.0010	0.9223
Outcome	**NL**	**NL**	**NNL**

Figure 31: Changes in total fish biomass. The sum of the HADD and compensation site biomasses were compared to the control, as the HADD site retained some productivity following project implementation (vertical dashed line) and the compensation site contained some fish prior to restoration (top panel). T-tests compare the mean difference between pre-project and each of three post-project monitoring periods (2-tailed, df=10, t_{crit}=2.228). P-values indicate significance. Of the significant results, negative t-values indicate a net loss. A net loss of biomass persisted for six years after project completion, but no-net-loss was achieved by year 10 (bottom panel).



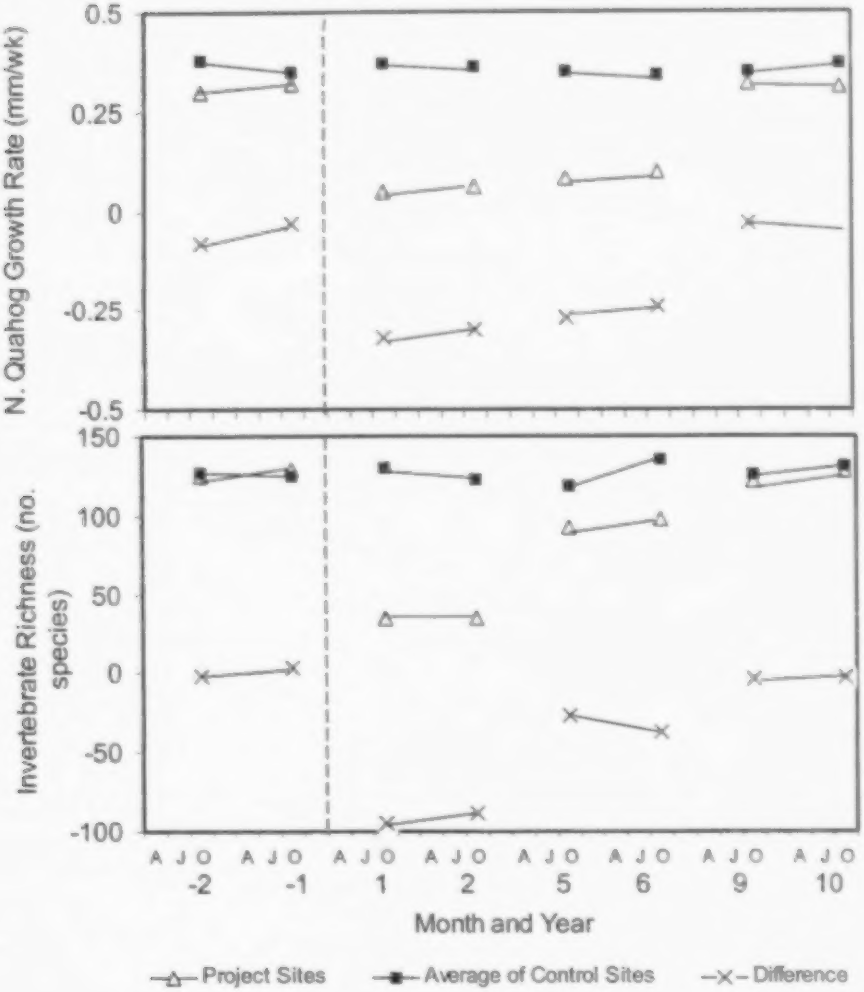
	Area			Stem Density		
Year	**1-2**	**5-6**	**9-10**	**1-2**	**5-6**	**9-10**
D_A-D_B	134.15	77.71	170.03	-777	-806	-303
SE	10.63	3.46	4.54	57.6	56.9	50.45
t	12.62	22.43	37.48	-13.48	-14.18	-6.00
p	<0.0001	<0.001	<0.001	<0.0001	<0.0001	0.153
Outcome	**NG**	**NG**	**NG**	**NL**	**NL**	**NNL**

Figure 32: Changes in eelgrass bed area (upper panel) and stem density (lower panel) following project construction. T-tests compare the mean difference between pre-project and each of three post-project monitoring periods (2-tailed, df=10, t_{crit}=2.228). P-values indicate significance. Of the significant results, negative t-values indicate a net loss. The high compensation ratio produced a large net gain in bed area following project completion, but severe plant losses in the new area occurred until year 6. In the spring of year seven lost areas were reseeded and a power boat ban enforced in the area. This halted area losses. Stem density was significantly reduced for six years following project construction, perhaps due to power boat impacts. No-net-loss was achieved by year 10 following the ban.



	Bivalve Biomass		
Year	**1-2**	**5-6**	**9-10**
D_A-D_B	-92.8	38.7	320.7
SE	38.3	27.2	23.7
t	-2.42	1.42	13.50
p	0.0361	0.1860	<0.0001
Outcome	**NL**	**NNL**	**NG**

Figure 33: Changes in bivalve biomass following project construction. The sum of the HADD and compensation site biomasses were compared to the control as the HADD site retained some productivity following project implementation (vertical dashed line) and the compensation site contained some bivalves prior to restoration (top panel). T-tests compare the mean difference between pre-project and each of three post-project monitoring periods (2-tailed, df=10, t_{crit}=2.228). P-values indicate significance. Of the significant results, negative t-values indicate a net loss. No-net-loss was achieved within six years and a significant net gain was established by ten years following construction, largely due to the high compensation ratio.



	Northern Quahog Growth Rate			Macroinvertebrate Richness		
Year	1-2	5-6	9-10	1-2	5-6	9-10
D_A-D_B	-0.26	-0.20	0.01	-92.5	-33	-4.5
SE	0.03	0.03	0.03	4.61	5.83	3.04
t	-9.47	-6.86	0.34	-20.07	-5.66	-1.48
p	0.0110	0.0206	0.7662	0.0025	0.0298	0.2770
Outcome	**NL**	**NL**	**NNL**	**NL**	**NL**	**NNL**

Figure 34: Changes in growth rate of northern quahog bivalves (upper panel) and of macroinvertebrate species richness (lower panel). T-tests compare the mean difference between pre-project and each of three post-project monitoring periods (2-tailed, df=2, t_{crit}=4.303). P-values indicate significance. Of the significant results, negative t-values indicate a net loss. Standard sized bivalves were obtained from a nursery and planted in pens at each site. Their growth rates dramatically reduced until after year six, but achieved no-net-loss by year 10. Macroinvertebrate species richness was drastically reduced following project completion but had achieved no-net-loss by the end of the monitoring period.

7.4.8 Conclusions

DFO biologists concluded that no-net-loss had been achieved by the end of the ten year monitoring period as all measured parameters had achieved no-net-loss and large net gains had been made for a number, including eelgrass area and bivalve biomass. The success of the project can be attributed to two factors: first, the large compensation ratio of 4:1 and second, a timely management intervention after year 6 when the project appeared to be failing. The ban on powerboats in the restoration area reduced high turbidity in the site, halting the loss of eelgrass area and allowing productivity to increase. The effects were best illustrated by the rapid gain in quahog growth rates and eelgrass stem density following the ban.

Although the impacts of the project on the primary target species, Atlantic salmon could not be quantitatively assessed due to its extremely low numbers, measurement of a range of indicator variables allowed assessment of overall project success.

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APPENDIX

APPENDIX 1. SUPPLEMENTARY STATISTICAL DETAILS FOR BACIP STUDIES

A1.1 Tests and analysis strategies for assumption violations in BACIP studies

Assumption	Test for Before Period Data	If Test Not Met
Additivity	Tukey's test for additivity (Tukey 1949, Stewart-Oaten et al. 1986)	Try transforming data. Use Box-Cox test (Zar 1999) to select transformation and re-apply Tukey test to check it. If this doesn't work, drop variable or apply regression methods (see Stewart-Oaten and Bence 2001)
Independence	Durbin-Watson test for serial correlation (Durbin and Watson 1971)	Average some neighbouring values or Transform to approximate independence (see Stewart-Oaten et al. 1986) or Use more elaborate intervention analysis (see references in Stewart-Oaten et al. 1992)
Identical Normal Distributions	A. Test for significant skewness or kurtosis (Zar 1999)	If minor, ignore as t-tests are quite robust. If strongly skewed apply modified Welsh t-test (Cressie and Whitford 1986)
	B. Do distributions change between periods Are number of sampling times equal in before and after periods? Test for equal variance in before and after periods (Zar 1999)	Use Welsh t-test
	C. Do distributions change within period? Test for equal variance among samples within periods	Use Welch t-test and If degrees of freedom <30 understand that probability of finding an effect where none exists (α) is actually higher than nominal value in test

A1.2 Significance Testing

In BACIP and ACI studies statistical significance is typically tested for using either a parametric t-test or a non-parametric U test, although other, more complex, methods using regression or intervention analyses are required when key assumptions are violated (see appendix 2 and Stewart-Oaten et al. 1992). The t statistic is calculated as

$$\text{(A1.1)} \qquad t = \frac{(D_A - D_B)}{SE}$$

where D_A and D_B are the mean differences between project and control values in the after and before periods and SE is the standard error of the estimated effect size, calculated as

$$\text{(A1.2)} \qquad SE = \sqrt{S_p^{\,2}\left(\frac{1}{n_B} + \frac{1}{n_A}\right)},$$

where s_p^2 is the pooled variance of the before and after periods, and n_B and n_A are the number of samples in the before and after periods (adapted from Zar 1999). In the (likely) event that variances are unequal in the before and after periods and/or the distributions are non-normal, *SE* is calculated as

$$\text{(A1.3)} \qquad SE = \sqrt{\left(\frac{S_B^{\,2}}{n_B} + \frac{S_A^{\,2}}{n_A}\right)},$$

where S_B^2 and S_A^2 are the variances among samples in the before and after periods respectively (Cressie and Whitford 1986). This is the Welch t-statistic and in most cases is more reliable than the classic t-test for BACIP designs (Stewart-Oaten et al. 1992). Regardless of how it is calculated the t statistic is compared to the t_{df} value read from a t table for the desired α level (see below) with

$$\text{(A1.4)} \qquad df = (n_A + n_B) - 2\,.$$